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THE EFFECTS OF ICING ON COMMERCIAL FISHING VESSELS

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Abstract

Ice accretion on commercial fishing vessels is a problem faced by fishermen in cold climates. The U.S. Coast Guard has standards that pertain to the amount of icing fishing vessels must be able to safely accrete without capsizing. Using research on past vessel incidents and historical weather data, we have assessed the adequacy of the current standards and made recommendations to adjust U.S. Coast Guard standards on region, timeframe, and acceptable icing thickness on fishing vessels in Northeastern U.S.

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Executive Summary

Commercial fishing is the most hazardous occupation in the United States (Bureau of Labor Statistics, 2008). With the demand for seafood leading to substantial monetary benefits, fishing vessels commonly voyage out in harsh weather conditions. One such hazard that commercial fishing vessels are battling while at sea is the problem that can arise from the accumulation of ice on the vessels, which can lead to instability and capsizing. Casualties such as the sinking of THE LADY OF GRACE, a fishing vessel that sank due to icing in 2007, have motivated interest for the Coast Guard to evaluate the standards and regulations concerning icing (Jack Kemerer & Mike Rosecrans, personal communication, September 29, 2008).

One way in which the Coast Guard attempts to lower the risk of a fishing vessel incident occurring due to icing is through stability testing requirements. For the Northeast region of the United States, the U.S. Coast Guard currently requires fishing vessels over 79 feet operating north of 42°N latitude between November 15 and April 15 to maintain stability with an assumed thickness of ice in a theoretical analysis (see Appendix C for full regulations). Our goal was to determine the adequacy of this standards looking mainly at the region and timeframe limitations as well as the assumed thickness implemented in stability testing. We reviewed past icing incidents and historical weather data to identified trends amongst them that were conducive to icing as well as consulted with experts in the fields of naval architecture and meteorology.

Looking at weather data before and after November 15 and April 15, we found no supporting evidence to show icing would be a high risk outside of this five month period in the

Northeast U.S. and there for concluded the current timeframe is adequate and needs no adjustment. We also looked at weather data south of 42°N latitude analyzing the archival data available from NOAA's buoy website. We were able to see and when events that would favor the accumulation of ice would occur. By analyzing the frequency and severity of the events we concluded that the current latitude limits is inadequate and that icing for is a danger for fishing vessels south of 42°N latitude and recommend it to be lowered to include all vessels traveling north of 38°N latitude.

By analyzing past icing incident reports we noted significant differences between the amounts of ice build up in actual occurrences compared to the assumed stability thickness. We also spoke with experts in the fields of naval architecture who commented on the adequacy of the current criteria used in stability testing. We could make no conclusion on the adequacy of the assumed thickness used in testing, however we recommended the Coast Guard further research the adequacy of assumed ice loading as well as other stability criteria in the regulations.

Lastly, we analyzed how adequately the Coast Guard is educating commercial fishermen on the issue of icing and concluded the Coast Guard is doing more than a sufficient job through weather warnings, educational flyers, and articles in various periodicals. Ultimately we feel these conclusions and recommendations may help the Coast Guard to lower the risk of an icing incident occurring particularly in the fishing areas off New England.

1 Introduction

Commercial fishing is currently the countries' most hazardous occupation (Bureau of Labor Statistics, 2008). From fierce storm conditions to rough waves, weather increases the risk of danger faced by fisherman during a voyage. Some aspects of the dangers fishing vessels face can be avoided, and ships can be strengthened to take on harsh situations. Regulations have been promulgated regarding the design and safety equipment of a fishing vessel to aid in avoiding the misfortunes the ocean can cause. The importance of a safe vessel cannot be overlooked because of incidents such as the sinking of the LADY OF GRACE, which claimed the lives of its four-man crew in January of 2007 (United States Coast Guard, 2007b).

There is no one specific hazard that commercial fishing vessels face in cold regions. There are several contributing factors and conditions that lead to an array of problems for fishermen. One of the crucial hazards encountered by vessel operators is the phenomenon known as icing (United States Coast Guard, 2008b). The accumulation of ice on a vessel's superstructure can lead to tragic incidents such as capsizing caused by instability. While only two of approximately 200 vessels lost to capsizing in the last 15 years in the northeast region of the United States were believed to be attributed directly to icing, this still remains a problem issue for commercial fishing vessels as well as the Coast Guard since they are responsible for developing safety standards pertaining to icing.

Past research and analysis has led to standards and technologies which have been used in an effort to prevent and reduce icing. One way in which this problem is being combated is by electronic systems which use heated surfaces to counter icing within certain ranges of temperature and wind. The Coast Guard has implemented this system on their own vessels in the Great Lakes and Alaska regions (United States Coast Guard Academy, 2008). Another approach by which they have attempted to solve this problem is that they require an assumed thickness of ice in stability analysis for vessels over 79 feet in the Northeast United States (Jack Kemerer and Mike Rosecrans, personal communication, September 29, 2008). The LADY OF GRACE, being shorter than 79 ft., did not fall into this category, which is one of the currently known inadequacies of the 1991 regulations. As a result, the Coast Guard has begun to extend the standards to include any vessel over 50 feet in length. Since the tragedy of the LADY OF GRACE sinking, numerous other comments have been made by numerous Coast Guard officials and naval architects on the validity of the current stability standards.

There has been little research done since the early 1990's on the issue of icing. This could be explained by the rare occurrence of a boat sinking due to icing. However, because of the incident involving the LADY OF GRACE, the Coast Guard has deemed it necessary to re-examine current standards. According to fisherman and United States Coast Guard officials the current regulations may not be adequate in some aspects. There has been approximately a twenty year gap in research done by the Coast Guard on the issue of icing, which is why it was crucial to obtain more current data and information.

It was our goal to determine the adequacy of the 1991 Coast Guard icing standards and stability for vessels over 79 ft. and subsequently recommend any alterations (if any) that should be made. We set out to achieve this weather data to predict the rate and amount of icing that can occur. There were three main objectives we identified in order to achieve our goal. First, we identified the impacting factors of each past icing casualty on record, looking for any similarities. Second, we determined severe weather factors that lead to icing. Then we graphed the weather data correlating it with time of the year as well as the region where it was occurring. Third, we identified the stability criteria set forth in the 1991 standards. Using the current criteria used for predicting icing, we attempted to identify any inadequacies that could have led to errors through the use of expert opinions and past case studies. By achieving these objectives we were able to confidently determine inadequacies in the 1991 Coast Guard icing standards and suggest some modifications to these standards that could reduce the chances a fishing vessel accident would occur due to problems related to icing.

2 Background

In this chapter we cover the background of the issue of icing and how it affects the commercial fishing industry as well as the Coast Guard (see Figure 2-1). The first section discusses broadly the dangers crew members of fishing vessels face as well as how icing as affected the industry in the past. Looking further into commercial fishing we analyze how human responsibility plays a role in the level of safety beyond the regulations and available technology. Next, we review the United States Coast Guard's responsibilities on the water, from maritime law enforcement to how they are currently dealing with the risks of icing. After that, we discuss situations outside fishing safety that have icing problems, more specifically wind turbines, airplanes. We present how foreign countries handled the problem of icing. The last section of this chapter deals with the effects of icing on the stability of a fishing vessel.

Figure 2-1: Moderate ice build up on the deck and railings of a vessel.

(photo courtesy of the Fishing Vessel Safety Division of the USCG)

2.1 Commercial Fishing

Commercial fishing in cold regions all over the globe entails serious risks. In the United States these hazardous conditions and circumstances are particularly common in the waters surrounding Alaska and areas of New England. Commercial fishing continues to be one of the most dangerous occupations in the country today (Bureau of Labor Statistics, 2008). This is in large part due to the operating conditions commercial fishing vessels face in cold regions.

Temperature is a determining factor of these harsh conditions, but it is only one factor that contributes to the hazards in cold regions (Compher, 2007). Other pivotal variable that augment the challenges faced in these regions are isolated fishing grounds, seasonal darkness, cold waters, high winds, icing, fatigue, and short fishing seasons. The combination of these factors makes commercial fishing costly in several different ways. Due to these conditions the commercial fishing industry is vulnerable to crucial losses.

Fisheries can suffer from the damage or loss of vessels, equipment, catch, and, most importantly, crew. In 2007, 61 commercial fishing vessels were lost in the United States (Hickey, 2008). More importantly, that year the commercial fishing industry had a fatality rate of 111.8/100,000 workers (Bureau of Labor Statistics, 2008). More than half of these deaths were due to boats flooding, sinking, or capsizing. This fatality rate eclipsed the national average of 3.7/100,000 workers in other industries and shows that this is a serious problem that needs attention. Although fatalities associated with commercial fishing in cold regions are the main concern, there are other problems that need be addressed.

Most fishermen rely on their catch as their main source of income and well-being (Kemerer & Rosecrans, personal communication, November 17, 2008). Therefore, the vessels and equipment they operate are necessary tools for them to achieve success. Conditions in cold regions can damage and even destroy these tools that the men and women count on for their livelihood. As a result, the monetary damages must also be considered as part of the problem of commercial fishing in cold regions.

Offshore fisheries, more specifically the shellfish fisheries, have a significantly higher fatality rate due to the fact the harvesting season for most species of crab is during the winter months (Hickey, 2008). In addition, the mass and structure of the vessels along with the equipment that is used on the vessels increases the risk factors. For example, the steel traps used on these boats weigh up to 800 pounds when empty, requiring cranes and heavy machinery to move them. The superstructure and stacks of traps can result in ship instability especially if combined with harsh weather conditions such as icing. Yet, the structure and mechanics of commercial fishing vessels are not the only contributors to hazards encountered in cold regions.

As a result of short fishing seasons, fishermen must harvest as much as possible in a short period of time. Due to the time constraints and narrow window of opportunity, commercial fishermen tend to take serious risks (Kemerer & Rosecrans, personal communication, November 17, 2008). They often make trips regardless of weather conditions and are typically at sea for long periods of time without rest (see figure 2-2). The resulting fatigue can affect the body and mind of fishermen. They may become weaker and less aware of their surroundings. At times, they may also overload the ship to increase their catch because they have to take advantage of the opportunities that arise. Although this strategy may seem irrational, it is unfortunately the nature of the commercial fishing industry. These men and women provide a commodity that is in constant demand, and they rely on the sale of their catch to provide for them. Commercial fishing is a way of life, so it must be understood in that light when designing measures to increase the safety of fishing vessels and crew members.

Figure 2-2: Vessel operating in a cold climate region experiencing rough waves.

(photo courtesy of the Fishing Vessel Safety Division of the USCG)

2.1.1 Background of Icing in Commercial Fishing

Although a rare cause of vessel sinking, ice build up is a common occurrence for commercial fishing vessels in cold climate regions (BMCM Bruce Morris, personal communication, December 9, 2008). Commercial fishermen often take high risks and constantly voyage out to sea despite severe weather warnings from the Coast Guard and National Weather Service. In the last six years there have been four incidents where vessels have sunk or been grounded due to icing (Dave Dickey, personal communication, December, 9 2008). Three of the vessel sinkings occurred off the coast of Alaska while the most recent, involving the LADY OF GRACE, sank off the coast of Nantucket, MA. Due to high costs, advanced technology that is currently available cannot be afforded by every vessel at sea. The lack of affordable effective preventions against icing combined with the willingness to make risky voyages was ultimately the cause of these four incidents.

Alaska, which experiences far harsher weather conditions than New England, has been the location for three of the most recent incidents (Dave Dickey, personal communication, December, 9 2008). According to the National Oceanic and Atmospheric Administration (NOAA) icing is most likely to occur with an air temperature below -1.7°C and sea surface temperature below 7 °C and wind speeds above 9.7 m/s (Guest, 2008). The addition of freezing sea spray, various forms of precipitation, and wave height also affects the amount of probable accretion.

In 2002 the TRADEWIND, a 51 foot vessel, experienced severe ice build up due to below freezing temperatures and heavy seas washing over the vessels deck and freezing (United States Coast Guard, 2002). The accretion of ice on the hull caused the vessel to become unstable. The crew was unable to break off the ice and in an attempt to slow the build up the captain of the boat attempted to veer away from the harsh conditions. While turning, the vessel began to roll to its starboard side and subsequently capsized and sank. While all three persons on board survived, the loss of the vessel was estimated $400,000. The other two vessels sank off the coast of Alaska in 2007. They were the HUNTER and STAR TREK and will be discussed later in this report.

The most recent and well known incident (also more thoroughly covered in chapter 4) was the sinking of the LADY OF GRACE in 2007. This incident involved a 75 foot vessel and claimed the lives of all four of its crew members (United States Coast Guard, 2007b). The vessel itself had been modified for scalloping operations and subsequently was submitted for a stability analysis to an independent Naval Architecture firm. Prior to the vessels departure there had been warnings of severe storm conditions involving low air and sea temperatures combined with freezing spray. The prolonged exposure to these conditions lead to a build up of more than two inches of ice on the super-structure and ultimately caused the vessel to capsize. Due to the failure of the deployment of two lifesaving devices: the electronic position indicating radio beacon and the inflatable life raft, the chance of survival for the crew was limited. This incident lead to various in depth reports into the issue of icing.

Currently the most commonly utilized methods to battle the accretion of ice on a vessel’s structure, hull, and deck is the use of wooden mallets or baseball bats to literally break off the ice (see figure 2-6). Another method for the mitigation and avoidance of vessel icing involves ship maneuvers (Guest, 2008). When severe conditions arise that favor icing, the best measure is to seek immediate shelter in a harbor or downwind of a land mass. If this is not possible, the next best course of action is to steam downwind to minimize sea spray.

Another means that are available to reduce icing are the use of preventative coatings (Guest, 2008). Fluorocarbon penetrating coating and Vellox 140 are two ice fearing coatings that can be applied to the vessel hull and super-structure to repel water and prevent ice build up (these two specific coatings are recommended by the U.S. Navy). Other tools that can be used in the removal of ice are scrapers, shovels, spades, hoes, picks, and brooms. Much like one would take care of icing on their walkway at home, it is also recommended to use rock salt, or a fast acting alternative calcium chloride. Most chemicals contain alcohol and have been known to be corrosive, but there are less corrosive alternatives such as urea.

Weather is an unavoidable factor of commercial fishing unless one simply does not voyage out. The phenomenon of ice build up, although a rare cause of marine casualties, is a common occurrence on vessels in cold climate regions. There are affordable tools and simple methods to avoiding ice, but they are not always effective in absolute prevention and removal. The National Oceanic and Atmospheric Administration as well as the Coast Guard and Navy issue awareness flyers and reports in an attempt in lower the risk of such casualties. As long as fishermen continue to take the risk of voyages during severe storms, icing will always be an issue.

2.1.2 Coast Guard's Involvement with Commercial Fishing

The Coast Guard's responsibility on the water has an unparalleled importance when it comes to saving lives. Their motto: *semper paratus*, which means *always ready,* is a testament to their mission in the deep seas (United States Coast Guard, 2008a). There are specific units of the Coast Guard that are dedicated to commercial fishing safety. The members of these sections of the Coast Guard work to protect crew members of the vessels as well as ensure regulation compliance. They have worked throughout the years attacking every angle of safety, from response time to putting in place standards that prevent dangerous situations.

One of the concerns the Coast Guard is facing right now is the issue caused by the accumulation of ice on fishing vessels in cold climate regions. The Coast Guard has enacted standards as to the thickness of ice they require in stability testing; however because of incidents such as the tragedy of the vessel LADY OF GRACE, the Coast Guard is concerned that existing standards are inadequate (Kemerer & Rosecrans, personal communication, September 29, 2008).

The Coast Guard icing standards, published in 1991, apply to the Northeast Atlantic and Northwest Pacific fishing regions (see Appendix C for full regulations). For the Northwest Pacific region, Commercial fishing vessels over 79 feet operating north of 66°30' North latitude between November 15 and April 15 must submit their vessels for a stability analysis. In the analysis they must maintain stability with an assumed thickness of 1.3 inches of ice spread across the horizontal surfaces and 0.65 inches of ice spread across the vertical surfaces (these thicknesses correspond to 6.14 lbs/ft.^2 and 3.07 lbs/ft.^2 respectively). The horizontal surfaces pertains to the deck and top of cabins and/or super structure and vertical surfaces pertain to the hull , walls of cabins and/or super structure, as well as the riggings of the boats. For vessels traveling in the Northeast Atlantic, the time frame in the regulations remains the same; however the assumed thicknesses in stability analysis are halved due to far less extreme weather conditions. This corresponds to a horizontal assumed thickness of 0.65 inches (3.07 lbs/ft.^2) of ice and a vertical assumed thickness of 0.325 inches (1.535 lbs/ft.^2) of ice. The height of the center of gravity should be calculated according to the position of the assumed accumulated ice as defined in the regulations.

The standards that are promulgated by the Coast Guard are implemented in a way to avoid as much as possible the search and rescue route of saving lives. Although in a perfect world, each crew member of a commercial fishing vessel would be knowledgeable of the rules and regulations of the ocean; this is not always the case (Jack Kemerer, personal communication, December 18, 2008). When marine safety incidents occur, it could be argued that the aftermath of the event is just as important as the accident itself. Reports written by officials of the USCG are essential in accident prevention. Each archive contains detailed information about all relevant data on each specific incident. Procedures like this are just some of the tools that the United States Coast Guard employs to prevent future incidents.

One office of the Coast Guard that is vital to aiding a vessel in distress is the search and rescue division, which is probably the most recognized section of the Coast Guard (United States Coast Guard, 2007d). The search and rescue division falls under the “Safety” category of the Coast Guard, as defined in their 2007 report. In 2006, the United States Coast Guard responded to over 28,000 search and rescue cases, rescuing 85.3% of those at risk. These cases can range from recreational boating to commercial fishing, but it also should be noted that the rate of deaths and injuries has declined over the past 5 years. The Coast Guard believes that by constantly improving its technology and other measures, they have played a key role in this decreasing trend.

One such improvement was in 2006 when the Coast Guard instituted “Rescue 21” and “Project Deepwater” (United States Coast Guard, 2007d). Utilizing GPS (global positioning system) and advanced communication technology, Rescue 21 covers over 20,000 miles of United States coastline. Through satellite communication, distress signals are relayed and direction finding computes the line of bearing. The distress call, as well as the line of bearing, is sent to the nearest Coast Guard ground center, and the necessary units are dispatched to aid the victims. Rescue 21 also replaces obsolete forms of communication such as FM transmitters.

Much like Rescue 21, Project Deepwater’s purpose is to seek out and replace all obsolete vessels and aircraft, as well as modernizing command, control, and logistic systems (United States Coast Guard, 2007d). The 25 year program’s goal is to recapitalize all USCG assets. With $24 billion invested in the program, the Coast Guard has been working with independent companies to upgrade equipment from land to air. The upgrades will be linked intelligence systems for better communication and execution. Innovations such as Rescue 21 and project Deepwater clearly show how the Coast Guard is constantly making improvements that adapt to the needs of the people they serve.

While the USCG serves everyone on the water, there are specific areas in which special attention is focused. Commercial fishing is one of the most dangerous occupations as well as one of the only methods to retrieve a vital food resource. It is no surprise that the Coast Guard has a whole unit dedicated to the safety of the crew members of these vessels (United States Coast Guard, 2007d). The Coast Guard certifies over 200,000 mariners through the Merchant Mariner Licensing and Documentation program. Although the majority of vessel operators are not required have a license, the captains of vessels over 200 gross tons are required to have one. Working in conjunction with various agencies as well as state and local governments, they strive to ensure safe practices.

The USCG also provides a safer trip on the water through warnings. A warning that is constantly provided by the Coast Guard to mariners is that of harsh weather conditions. However, they have gone even further to warn fishing vessels of potential icing when necessary (South Coast Today, 2008). The Coast Guard is constantly working in conjunction with NOAA (National Oceanic and Atmospheric Administration) to broadcast the probability of icing conditions. As mentioned above, the issue of icing on commercial fishing vessels is something the Coast Guard has been working to solve as of late. The occupation of commercial fishing demands a year-round duty, which is why vessels must go out despite of the cold weather. Capsizing and instability have led to numerous vessel accidents, and the warnings the Coast Guard supplies on icing are just another method they use to ensure safety.

Some measures go beyond rules and regulations as science has played a key role in aiding the Coast Guard in its battle with the hazards of the sea. Besides the previously mentioned advances the Coast Guard has made, there are actually improvements that are currently being implemented out on the ocean. One such instance is the "Buoy-Deck De-Icing System" for USCG 225' Buoy tender, an electrical system used in the Great Lakes and Alaska as a tool against icing (United States Coast Guard Academy, 2008). The system prevents ice formation down to 0 degrees Fahrenheit with 15 knots of wind countering with a heat load of 250 kilowatts. This has undoubtedly been an invaluable technology in the winter months. It is important to note, however, that this technology is not available to commercial fishing vessels (Mike Rosecrans, personal communication, November 17, 2008).

Although it is impossible to make the waters themselves safer, the United States Coast Guard undoubtedly does everything it can to make sure that those who travel the ocean are safe. On average, every day the Coast Guard saves 14 lives, conducts 24 marine casualty investigations and assists 98 people in distress (United States Coast Guard, 2008d). Their role in society has an invaluable importance when it comes to ensuring human safety, law enforcement, and environmental pollution prevention.

2.1.3 Human Factors in Commercial Fishing

The United States Coast Guard's Rules and Regulations can only go so far to lower the risk of dangers encountered on the open water by commercial fishing vessels. There has to be cooperation between the fisherman and the Coast Guard. This means proper training and an understanding of the responsibility that such a hazardous occupation entails. Proper qualifications have to be met by every licensed fisherman, but once on the water the human factor plays a huge role in the safety of a voyage.

The very first aspect that one must take into consideration when measuring how much the human factor adds to the equation is that not every crew member on a commercial fishing vessel will always meet the legal qualifications mandated by the United States Coast Guard (Jack Kemerer, personal communication, December 18, 2008). Although disregarding some laws such as catch limits and citizenship might not play a role in safety, the lack of proper training could lead to serious consequences. Because the Coast Guard can only do so much through rules and regulations, they have to be met halfway by the cooperation of fisherman out on sea. To obtain a commercial fishing license fisherman must meet certain qualifications that ensure they understand the proper conduct while at sea. This is just one instance where cooperation between both parties must be maintained.

The necessity for every fisherman on a commercial boat to have the proper training and qualifications is demonstrated by the severity of the fines and punishments handed out for disregarding the law. The cost of violating clear-cut regulations set forth by the USCG can be up to $10,000 depending on the infraction (Marine Link, 2003). The Coast Guard monitors that their rules are being followed through exercises such as routine random boardings. These inspections are a useful tool to ensure that each boat has proper safety equipment, such as the correct number of flotation devices, which are vital in aiding in search and rescue.

One case where an inspection carried out by the Coast Guard prevented a possible volatile situation from occurring was in 2003 when a ship was found in violation of numerous regulations (Marine Link, 2003). While on patrol, the USCG cutter Moray conducted a routine boarding of two ships diving for sea urchins off the coast of Maine. Both vessels lacked the proper number of fire extinguishers, had expired distress signals, and incorrect markings on their life rings and flotation devices. The two boats' voyages were put to a halt, and they were escorted back to their home ports by Coast Guard authorities. This was just one instance where a situation was averted because of the USCG, but it also shows how the human responsibility factor could have possibly led to a tragedy.

Another area of human responsibility that could possibly cause serious issues is the fatigue factor (Mike Rosecrans, personal communication, November 13, 2008). The duration of the shifts one crew member might endure are not eight hours long like many others, but can last up to 12-15 hours. The hindrance and toll on the mental state of experienced by a fisherman can be compared to that of the effects of alcohol. Judgment and one's self realization of their surroundings cannot be relied on and that is when accidents occur. This area of human responsibility relates back to the choice all fishermen make when they take on the known risk that is involved in commercial fishing.

When seconds count, every little aspect of how a situation is handled matters. When routine exercises like proper evacuation procedures are followed correctly, the chance of survival is raised that much more. The Coast Guard will always do their best on their end of an operation, but cooperation of the crew members is just as crucial for lives to be saved.

2.2 The Effects of Icing outside New England Commercial Fishing

Although the effect of icing is a prevalent factor faced by vessels in cold climate regions all over the New England coastal region, it is not the only area where there is an issue. Besides the other similar areas of the world such as the Arctic and Northern Pacific regions, there are actually other examples of technology that encounter problems from icing. One such example is that planes attempting to take off in the winter season must go through de-icing procedures. Other areas that also experience this problem are power lines and wind turbines. While in each of these instances there are broad differences in how they are affected, they share key similarities in the current solutions to their respective scenarios.

2.2.1 Canadian Coast Guard and the National Research Council of Canada

In June of 2005, the National Research Council of Canada (NRC), working in conjunction with the Canadian Coast Guard (CCG), published a report detailing past incidents in the coastal Canadian region. Much like the cause for the United States Coast Guard's current research into this area, this report was brought about by the fact there have been more than 1000 incidents caused by icing since 1970 (Kubat & Timco, 2005). Through tools such as models that estimate ice accretion and questionnaires that were given to fisherman who had first-hand experience, the NRC and the CCG have been battling this issue as long as the USCG.

Two of the models implemented by the Canadian Coast Guard are RIGICE and ICEMOD, both which are used to simulate and predict icing. Although these are not exclusively used by the CCG, both tools were highlighted in the 2005 Marine Icing Database report (Kubat & Timco, 2005). ICEMOD was developed by SINTEF's polar group, a division of an independent research group based out of Scandinavia (Eidnes, 2008). It is a one-dimensional tool which models ice accretion on cylindrical areas as well as horizontal and vertical surfaces. For an icing predictor to work accurately it must simulate certain factors to a specific level such as high wind speed, low air temperature, and low water temperature. With the use of simple algorithms such things like expected icing rates and icing risk classes can be determined. In a 2008 report published by a representative of SINTEF Grim Eidnes praised the value of ICEMOD as well as RIGICE.

SINTEF also employs other methods of de-icing that prescribe the use of chemical compounds (Eidnes, 2008). The type of compound which is used depends on two factors: chemical makeup of the given surface as well as the actual texture. The chemical deployment is effective by introducing a low surface energy variable and by simulating a rough surface between the substrate and ice itself. The purpose of the introduction of this rough surface is that it creates air between the ice and substrate, which makes it more difficult for the ice to accumulate. Other areas in which SINTEF is attempting to counter the accumulation of ice involve freezing point depression fluids and high pressure water jetting. They also employ mechanical devices, and thermal and electrical techniques such as heaters and electro pulse techniques.

In the 2005 Nation Research Council of Canada's (NRC) report, another way in which the problem was researched was through questionnaires handed out to fishermen (Kubat & Timco, 2005). Jim Stallabras, a member of the NRC, published a report in 1980 which described the collection of ice on fishing vessels off the eastern coast of Canada. This report was very useful due to the collection and analysis of questionnaires answered by fisherman in the concerned region. The questionnaire basically requested information on first hand experiences of icing by the crew members, which in turn was reported back to the NRC. The report that followed was one of the first of its kind, establishing a relationship between icing and environmental conditions and correlating it with geographical regions. The report was archived after its publication and just recently it was retrieved to aid in current research. Because of the uniqueness of the of Stallabras's findings, his work was vital to the NRC's 2005 report.

2.2.2 Effects of Icing on Airplanes

Airports in cold climate regions, coastal and non-coastal, face issues caused by icing. The accumulation of ice causes hindrances to the physical aspects such as the aircrafts wings and take-off gear (Paula, 1997). When the wings build up ice, this can lead to an unsmooth flow of air and lack of lift that can lead to crashing. Similar to the methods employed in other areas, the airport crews utilize mechanical and chemical measures such as scrapers and chemical sprays. Another way which was not previously mentioned is the use of infrared systems to counter build up. A basic explanation is that through electromagnetic waves the transfer of energy between hot and cold surfaces is continually exchanged until both surfaces reach the same temperature.

2.2.3 The Effects of Icing on Wind Turbines

Apart from airplanes and marine vessels the collection of ice on wind turbines does pose a direct human threat. The main issue caused by ice build-up is the hindrance to the actual motor. The other issue that is of greater concern to human safety is when the ice is shed from the blades and could possibly be propelled into the air, more commonly known as "ice throw". One community in Ontario, Canada, is currently facing this issue and on their publication page they highlighted a couple of solutions to the issue such as heated rotor blades and shut down procedures (The Blue Highlands Citizens Coalition, 2004). This is not a prevalent issue in the United States due to the lack of human proximity to the turbines and milder climate conditions, however there are other parts of the world that face this issue.

In a Finnish article linked from the Canadian communities' publication page a more in-depth and detailed report on ice-throw can be found (Kröning, Seifert, & Westerhellweg, 2003). Although the actual aspects of the accretion of icing may not seem relevant due to the fact that the turbines are on land, the measures that are taken in prevention have a strong importance in cross-over research in areas such as commercial fishing safety. The two areas in which hazardous conditions can arise from icing on turbines as detailed in the report are icing throw from an operating turbine and ice shedding from an idling position. The methods which were used by the Finnish researchers involved correlating wind conditions with where fragments were landing. From this information control systems of the turbines can be altered, lowering the risk of a hazardous incident. Solutions they implemented from this research are much like the systems the Canadian Coast Guard use on their ships, which predict conditions in order to give crew members a chance to adapt to the situation.

2.3 Effects of Icing on Stability

One of the most hazardous conditions commercial fishermen face in cold regions is the phenomenon of ice accretion (The Society of Naval Architects and Marine Engineers, 2003). This occurs when a vessel accumulates ice on their superstructure or deckhouse due to sea spray and severe weather conditions. A full glossary of stability terms can be found in Appendix D. Typically, the conditions that lead to ice accretion are an air temperature of 0-28 degrees

Fahrenheit, a water temperature below 45 degrees Fahrenheit, and a wind speed above 18 knots. These factors allow sea spray to freeze and accumulate on the vessel exponentially quickly because of the increase in surface area due to the ice, which then hinders the vessel's stability.

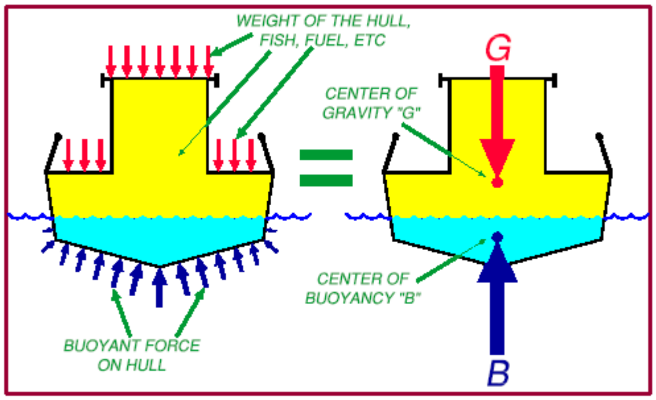

Figure 2-3: Relevant forces on a vessel's stability.

(source: The Society of Naval Architects and Marine Engineers, 2003)

Vessel stability is the ability of a ship to return itself to its upright position after being heeled over (The Society of Naval Architects and Marine Engineers, 2003). The two primary forces involved in vessel stability are gravity and buoyancy (see Figure 2-3). A vessel is stable when its center of buoyancy "B" shifts faster outboard than its center of gravity "G". Adversely, a vessel is unstable when the center of gravity shifts faster outboard than the center of buoyancy (see Figure 2-4a). The horizontal distance between the vessel's center of gravity and its center of buoyancy is referred to as the righting arm (see Figure 2-4b). A vessel is stable when the righting arm is positive, and it is unstable when the righting arm is negative.

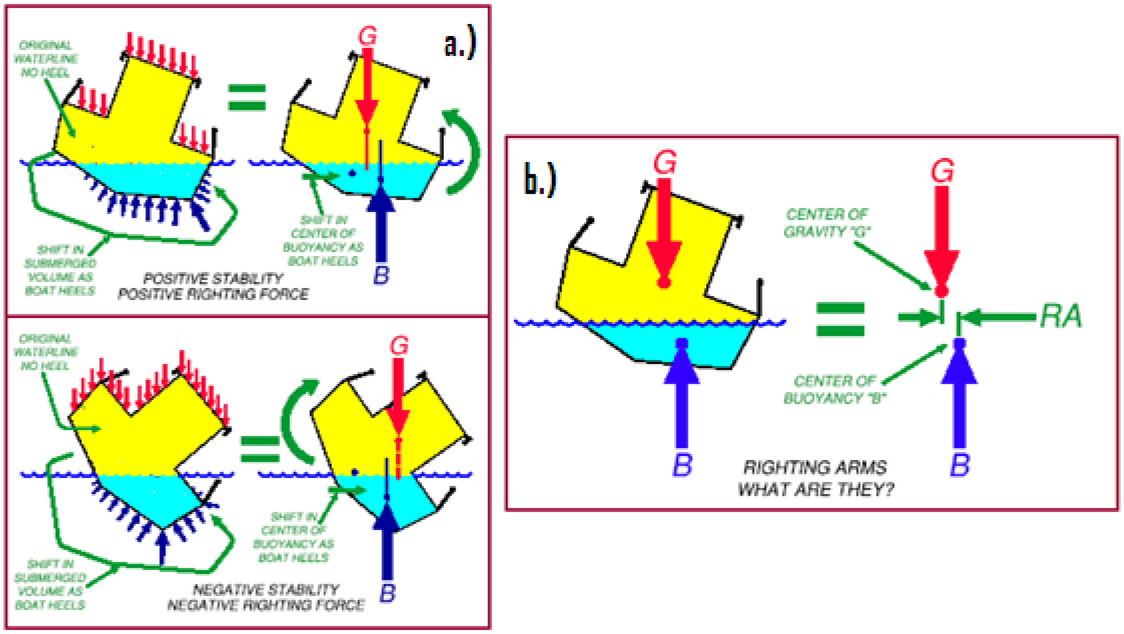

Figure 2-4: Positive and negative stability and the effects of gravity righting arm.

(source: The Society of Naval Architects and Marine Engineers, 2003)

Ice accretion can result in serious vessel instability leading to capsizing. The added weight of the accumulated ice, similar to overloading, raises the vessel's center of gravity and lowers its freeboard (see Figure 2-5). As the vessel's weight and center of gravity increases, the righting arm decreases which means the center of gravity begins to shift outboard faster. Once the righting arm is less than zero, the center of gravity shifts outboard faster than the center of buoyancy causing the vessel to capsize. The lower freeboard also causes the deck edge to submerge at smaller heel angles, which makes the vessel more likely to capsize. The effect of ice accretion on vessel stability is a serious danger that must be minimized when commercial fishing vessels are out at sea.

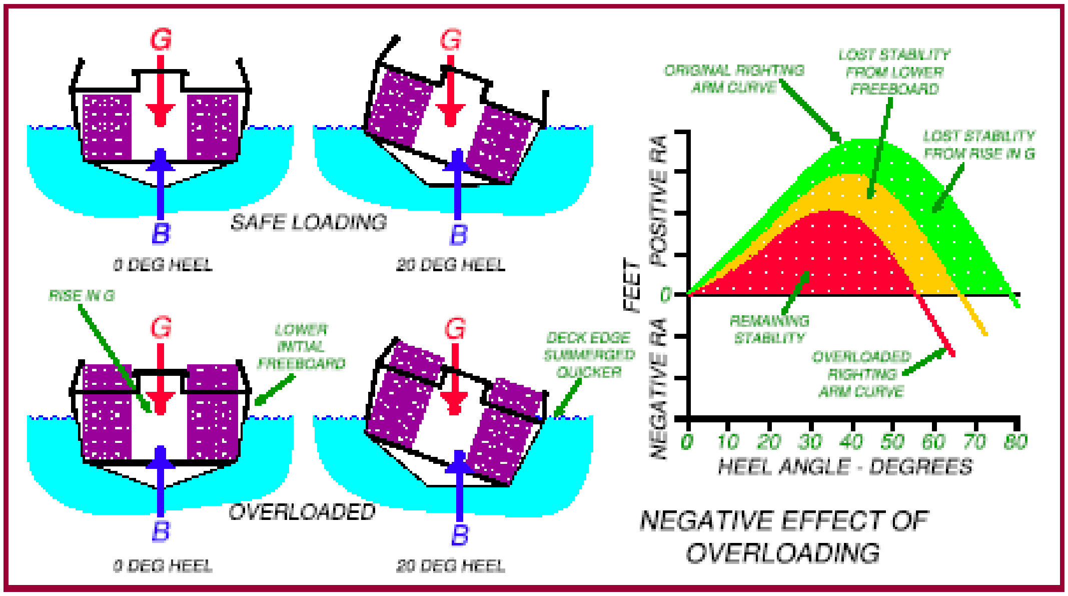

Figure 2-5: Effects of additional weight.

(source: The Society of Naval Architects and Marine Engineers, 2003)

2.4 Summary

Currently the Coast Guard is trying to reduce the dangers of vessel icing by creating new regulations and technology. However, their efforts will go to waste without the cooperation of the fisherman. Since the 1991 icing standards has in place are over fifteen years old, the Coast Guard believes that new research needs to be done to solve this problem.

Figure 2-6: Crewmembers breaking ice off of a vessel's railing with mallets.

(photo courtesy of the Fishing Vessel Safety Division of the USCG)

3 Methodology

The goal of this project was to determine the adequacy of the 1991 Coast Guard icing stability standards for vessels over 79 feet in length and to recommend any revisions or amendments based on our findings. To achieve our goal we identified three objectives:

a.) To identify the contributing factors in past icing incidents, accounting for human error as well as other unavoidable factors.

b.) To determine the severe weather factors that led to icing, focusing on the major contributing variables.

c.) To compare the stability criteria in the 1991 Coast Guard standards with the current icing predicting equations in use in order to evaluate time, region, and assumed thickness criteria.

We developed a methodology to help us evaluate the 1991 standards that took into account these factors. We incorporated the ideas and concerns of the Coast Guard as well as those of stakeholders in the commercial fishing industry.

3.1 Causes of Past Icing Incidents

Our first objective was to review past vessel incidents that were believed to be attributed to icing in order to identify not only key factors that caused the accidents but also to determine if there were any other causes such as human error. We reviewed four cases where icing was a major contributing factor to the accident. As a follow up to reading the casualty report of the LADY OF GRACE, we also read a naval architect's stability analysis report, which went into more depth about specific causes of the incident.

3.1.1 Weather Related Causes of Past Icing Incidents

The first of several important aspects of the case studies we considered was the weather reports. By analyzing factors such as air temperature, wind speed, and wave height, information that lead to our conclusions and raised questions about the adequacy of 1991 regulations were revealed. By examining data available from NOAA we were able to compare weather summaries from each incident. Ultimately we were able to analyze scenarios that were faced by each vessel and identify similarities among the casualties.

We focused on the professional opinions of the investigating officers and the safety examiners provided in each report. When the Coast Guard conducts an investigation into an incident, they often seek information from safety examiners and include their observations and subsequent recommendations. By analyzing each conclusion and recommendation made by the Coast Guard officials we were able to summarize the opinions of the role that icing played in the incidents.

Another aspect of our research was an investigation into the human factors that played a role in the outcome of each incident. By analyzing the casualty reports of each incident we were able to find where human behavior and decisions were main contributors to the incident. Reviewing areas where human factors came into play also helped us distinguish between inadequacies in the current icing standards and the contribution of human error.

Using the accident reports, we reviewed the stability analysis completed on each vessel by either private or Coast Guard Naval Architects. By analyzing the data collected on each incident concerning the vessel's stability characteristics we were able to identify certain similarities that contributed to each capsizing incident. In some cases improper stacking of traps and overloading led to a loss of vessel stability, on which the 1991 icing standards had no bearing. In other situations, vessels that followed proper loading procedures on their voyages and still capsized showed us where problems existed. It is important to note that the majority of the reports we analyzed did not include vessels over 79 feet in length to which the current USCG stability requirements apply to. By identifying instability as an issue on boats smaller than 79 feet in length, it helped us conclude whether or not the current standards provided a reasonable level of safety for these smaller boats. It is also important to note that numerous safety examiners have already recommended that the Coast Guard look into their standards to include all vessels over 50 feet in length.

3.1.2 Marine Safety Center Analysis

In order to better understand the LADY OF GRACE incident we conducted an interview with a member of the Coast Guard Marine Safety Center (MSC). When a vessel casualty occurs, besides the full casualty report that is produced, there may be a request for a more detailed look into certain aspects of the event by the experts at the MSC. In the case of the LADY OF GRACE, the MSC was asked to prepare a stability evaluation on the vessel. The marine safety officer assigned, LCDR Robert Compher, examined all factors and conditions of the incident and compiled a report that drew conclusions by looking at each aspect of the casualty.

The reason for talking with this officer was to obtain a better understanding of the assumptions made and the process used to make them. During this meeting we discussed his opinion of the incident and where he thought the current standards should be changed. We also shared the ideas we got from reading the report to see if our interpretations were valid. LCDR Compher recommended that we use the icing predictor as a main part of our research, an equation developed by Mr. James Overland of the National Oceanic and Atmospheric Administration (NOAA) that can predict the rate of ice accretion based on several weather factors. LCDR Compher also noted that the NOAA website had numerous resources we could use to retrieve weather data covering the past 25 years.

3.2 NOAA's Weather Data

When we first looked at NOAA's website we experienced difficulty interpreting the weather data, subsequently we to set up a meeting with a NOAA representative who had knowledge of the website as well as understanding of the data contained therein. Through the Coast Guard we were able to contact the official currently in charge of NOAA's marine icing sector of their marine modeling and analysis webpage. We met with Mr. Robert Grumbine and conducted a semi-structured interview that helped us better understand and interpret NOAA's weather data.

The icing casualty reports published by the Coast Guard utilized weather reports issued by the NOAA at the time of the incident as part of the analysis. When we met with the representative from the NOAA, we gained an understanding of the relationship between various weather factors and the accumulation of ice on vessels. We discussed various questions that we had on how we wanted to collect and analyze the data, such as how far back we should go and the frequency (months or weeks) that we should use when analyzing the data. Mr. Grumbine pointed us in the direction of specific aspects of NOAA's resources that he thought would benefit us the most.

3.3 Evaluation of Current Standards

The Coast Guard currently requires vessels operating north of 42°N latitude between November 15th and April 15th to be able to maintain stability with an assumed icing thickness of .325 inches. Using archival research and information retrieved from the interviews we conducted, we assessed whether the requirements in the 1991 Coast Guard standards provided reasonable safety guidelines. This was accomplished by looking closely at certain factors such as stability criteria and geographical and timeframe limitations (the full 1991 standards can be found in Appendix C).

3.3.1 Timeframe and Region

To determine if the current November 15 to April 15 timeframe is appropriate, we analyzed climate conditions 15 days before and after November 15 and April 15, respectively, to identify whether or not the time period should be extended or shortened. We specifically looked at sea surface temperature, air temperature, and wind speed during that time because those are the main variables that enter into the rate of ice accretion (Overland, 1989). We looked at daily averages recorded from NOAA at 38°N, 39°N, 40°N, 41°N, and 42°N latitudes in order to see if there was a high risk of icing which would indicate the dates should be amended.

NOAA lists weather thresholds, that when exceeded increase the probability of icing. We compared the monthly averages of these criteria against their respective thresholds for each latitude zone. We also recorded the frequency of events where conditions favored icing for at least 3 straight hours and graphed it based on region.

Similar to our time frame analysis, we recorded and graphed the frequency of events as they pertained to region looking as south as 38°N. We also took into consideration where the F/V LADY OF GRACE had sunk south of 42°N latitude. Using these two variables as well as analysis of additional examples of actual accidents, we were able to conclude whether the area of risk for icing needed to be expanded or not.

3.3.2 Stability and Minimum Thickness

By using data from all sources, we attempted to identify the adequacy in the 1991-defined icing thickness regulation. We compared the theoretical results that we obtained through the use of historical weather conditions combined with icing prediction equations against the current standard of vertical distribution of 0.325 inches of ice and horizontal distribution of 3.07 inches of ice. We also compared the theoretical data with the recorded experienced thickness from all available icing incident casualty reports. Through these comparisons we determined if there were significant differences between the calculated icing predictions and the actual icing incidents. We looked at three vessel incidents, the STAR TREK, the HUNTER, and the LADY OF GRACE, all of which sank at least in part due to icing. We also spoke with a Mr. Jon Womack, an expert in the field of Naval Architecture and LCDR Robert

Compher of the Coast Guard, who have experience with stability testing, on their thoughts of the current thickness.

3.4 Human Factors in Icing Incidents

Beyond the contributing weather factors that led to each of the four icing incidents we reviewed, we looked into on how human responsibility and error were contributors to these accidents. We analyzed specific areas of human behavior such as fatigue, drug and alcohol use, as well as a lack of training and safety awareness. We also discussed with our liaisons how much of an issue these factors were in the commercial fishing industry. Beyond that, we watched a video on the tragedy of the NORTHERN EDGE, a vessel that sank in 2004 believed to be mainly attributed to a lack of crew training as well as a lack of an understanding of current fishing policy (i.e. stacking procedures for traps). Through discussions with Coast Guard officials and by looking at the role human factors played in the three vessel incidents, we were able to identify areas where human factors tended to have a strong influence on the outcome of an incident.

3.5 Evaluation of C.G. Communication with Commercial Fishermen

The final aspect of our research involved looking into the communication between the Coast Guard and commercial fishermen. The purpose of this was to evaluate the sufficiency of Coast Guard's Role in spreading awareness of icing and other safety issues. We met with the members of the Fishing Vessel Safety Division of the Coast Guard to inquire what mediums they were currently using to communicate with commercial fishermen. We requested the forms of communication, detail, as well as frequency and region as to which they publish their literature.

3.6 Summary

Through these methods we determined the overall adequacy of the current icing standard as well as the quality of the Coast Guard's communication with commercial fishermen. Using research on past incidents as well as an analysis of archival weather data, we attempted to view our problem from every angle. We considered the impact of human factors as well, noting where they may have contributed to past incidents. Furthermore, we analyzed the current mediums the Coast Guard is using to spread safety awareness. In the next chapter we discuss the results of our research and analyze how it may be used to make fishing safer during winter months.

4 Results and Analysis

In this chapter we discuss the results from various areas pertaining to fishing vessel (F/V) icing that we researched. First, we discuss the contributing factors in the three case studies we reviewed. We identified three main weather variables: air temperature, sea surface temperature, and wind speed. Once all of these indicators pass a set threshold icing is most likely to occur. In each of the incidents we studied where these threshold were exceeded. We also identified various human factors that were contributors in each incident ranging from a lack of safety knowledge to illegal substance abuse. The second part of this chapter contains historical weather data going back as far as 23 years. By graphing these data we were able to identify specific regions and time frames where icing would pose a danger to commercial fishing vessels. The third aspect of our results and analysis contains a qualitative assessment of the current assumed thickness of ice that the Coast Guard requires vessels to be able to maintain stability with a uniform distribution in theoretical analysis. In final part of this chapter we analyze the sufficiency of the Coast Guard's job of spreading awareness of the issue of icing.

4.1 Contributing Factors in Past Icing Incidents

We reviewed in depth three vessel accidents: the STAR TREK, the HUNTER, and the LADY OF GRACE, all of which had occurred within the last two years and were mainly attributed to the accretion of ice. The incidents showed consistencies including but not limited to human responsibility error and severe weather conditions. After reviewing each of these incidents separately, we noted similarities among all three. It should be noted that the required thickness in stability analysis for vessels operating in the Northwest Pacific is twice that of vessels operating in the Northeast Atlantic.

4.1.1 Case I: F/V LADY OF GRACE

One of the main factors that influenced the Coast Guard to review the current icing standards in cold climate regions was the incident involving the LADY OF GRACE, a 75-foot fishing vessel which sank off the coast of Nantucket in January of 2007 (United States Coast Guard, 2007b). As a result of this incident, a full casualty investigation was completed by the Coast Guard. Numerous observations were made by several different Coast Guard representatives, which ranged from analyzing the current standards to improving the conveyance of the effects of icing in cold climate to fishermen. The full report, which was published a short time after, reflected the expert opinions of investigating officers, safety examiners, and naval architects.

The Coast Guard received and analyzed numerous forms of evidence that were crucial in arriving at their conclusions (United States Coast Guard, 2007b). Included in the information was, before and after photographs of the LADY OF GRACE, witness statements, and stability testing analysis reports by an independent naval architecture company. Weather reports were also analyzed that involved a trend analysis in various regions which focused on air temperature, wind speed, wave height, and water temperature among other things. There were two main aspects of the report that were relevant to the actual issue of icing beyond the data and evidence: recommendations and conclusions.

Among the various recommendations made by the investigating officers and safety examiners, it was clear that they agreed the current standards required a thorough review (United States Coast Guard, 2007b). The current standards pertaining to stability during icing only apply to approximately 5% of the fishing vessels because the standards only concern vessels that are greater than 79 feet in length. One of the main recommendations made by the Coast Guard officials was that they expand the regulations to apply to all vessels over 50 feet. The Coast Guard's office of vessel activities is currently reviewing these standards. In the current requirements, the Coast Guard defines certain areas by longitude and latitude in which vessels should expect to be able to accept a certain thickness of ice. Another recommendation that was made was that the current icing region be reviewed.

The current awareness of icing by the fishermen themselves was also brought into question. One of the main issues in the LADY OF GRACE incident was that certain safety devices did not function properly at the time of the incident (Ted Harrington, personal communication, October 22, 2008). In the report, officials requested that the Coast Guard look into better education on how to handle icing when it occurs. Lastly, it was stated that the Coast Guard should complete an analysis of casualty data involving icing in an attempt to correlate trends in other areas.

In addition to the recommendations made by the safety examiners, several conclusions were made based on the findings (United States Coast Guard, 2007b). One of the main problems with the vessel itself was that it had been altered in order to be able to become a scalloping vessel. The changes made to the vessel created a greater surface area, which lead to a greater accumulation of ice. Another conclusion made by the safety examiners was that the vessel, although less than 79 feet in length, would have failed the criteria set forth for a vessel over such a length. Lastly, it was concluded that the vessel was not properly fitted to be doing anything other than daytime scalloping, and it had been fishing at night.

In retrospect, the human factor also played a huge role in the tragedy. In a stability analysis of the vessel prior to the incident, numerous restrictions and limitations were noted for the boat to meet Coast Guard requirements during a day time scalloping voyage (United States Coast Guard, 2007b). Among the comments, it was noted that the doors to certain compartments be made watertight and that the boat required certain water and weight loading features. These comments were either ignored or misunderstood by the crew of the LADY OF GRACE, as the failure to comply with these recommendations was directly linked to the causes of the sinking. The life rafts and EPIRB, two life saving devices, were stowed in a area of the boat that was not water tight allowing them to become encased in ice, and therefore unable to deploy.

The tragedy of the LADY OF GRACE caused the Coast Guard to review the current standards originally published in 1991 (United States Coast Guard, 2007b). Although the Coast Guard can make standards more stringent, it falls on the fishermen to bear responsibility to comply with safety requirements in a dangerous profession. That being said, the Coast Guard realizes that human factors contribute to the majority of the accidents altogether, and therefore it is very hard to prevent them.

4.1.2 Case II: F/V STAR TREK

The second report that we reviewed was of the grounding of the STAR TREK, a 35-foot fishing vessel which lost engine power due to severe icing conditions off the coast of Alaska (USCG, 2007c). During a morning fishing voyage, the vessel accumulated extreme ice which led to a port list causing the engine becoming disabled. The crew members of the vessel were unable to break off the ice and, in an attempt to avoid sinking, the captain guided the vessel as it was drifting closer to shore and grounded the vessel.

Currently the Coast Guard is working on expanding their icing standards to include all vessels over 50 feet and it should be noted that this vessel would not fall under those standards mainly because a vessel of such length cannot physically take even a light accretion of ice (LCDR Robert Compher, personal communication, December 12, 2008). At the time of the incident, the nearest buoy weather buoy data, a device that records weather data, registered over that morning an average air temperature of -7 °C and an average sea surface temperature of 2 °C (NOAA, 2008). The recorded wind speed at the time of the incident was about 40 knots or 21 m/s (USCG, 2007c). According to NOAA, icing is most likely to occur with an air temperature below -1.7 °C, a sea surface temperature below 7 °C, and a wind speed above 18 knots or 9 m/s (NOAA, 2008). By computing the average of the air temperature, water temperature, and wind speed during the morning of the incident we were able to equate the likely rate of accretion the vessel was experiencing. The equation (see Equation 1), developed by Mr. James Overland in 1989, yielded moderate rate of ice accretion corresponding to a probable 0.3 – .8 in/hr of ice build up (A graph of the variance of ice accretion rates with respect to air temperature and wind speed at a fixed sea surface temperature of 2 °C can be seen in Figure 4.2.) As can be seen from the averages recorded during the morning of the incident, each variable surpassed its respective threshold for developing ice. There were also extreme wave heights as well as a light snow at the time of the incident. The validity of the thresholds provided by NOAA as well as the icing predictor is supported by the fact that at the time the vessel had grounded, it had taken on approximately 12 inches of ice (USCG, 2007c).

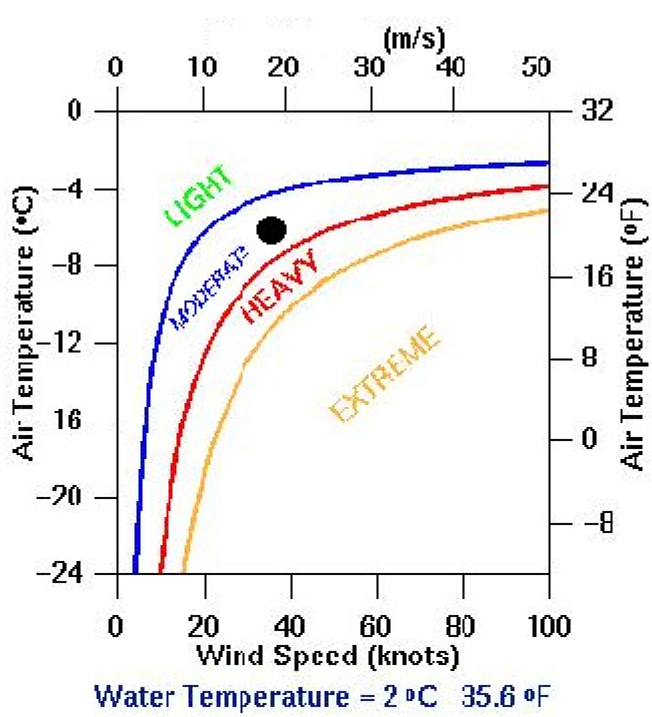

Figure 4-1: Nomogram of the various rates of ice accretion at a fixed water temp. of 2°C.

(source: Guest, 2008)

It is clear that there were extreme conditions present at the time of the incident and the STAR TREK's risk of capsizing due to icing would be would increased greatly due to its lack of size. The crew was physically unable to keep up with the removal of the ice on the vessel's structure, which in turn caused the boat to list, ultimately leading to loss of the engine's power. Whether a lack of training was the cause of the crew's inability to handle the icing is uncertain. From witness statements it seems as though the crew was prepared to handle the ice, but the conditions were just too severe. The captain of the boat also realized the imminent danger his crew and vessel were in, and in turn made the decision to go to shore to avoid sinking. This fact further indicates that weather was the major factor in this incident. Furthermore, we compared the weather data at the time of the incident to thresholds published by NOAA.

4.1.3 Case III: F/V HUNTER

The final vessel casualty report we reviewed was the sinking of the 58-foot fishing vessel HUNTER, a vessel that sank due to extreme icing conditions in the Shelikof Strait off the coast of Alaska (USCG, 2007a). The crew was en route to fish for cod when the vessel encountered high winds and freezing spray. The vessel became top heavy and began to list eventually leading to its sinking. There were no casualties as the crew donned immersion suites, gave a MAYDAY signal, and activated an emergency position indicating radio beacon (EPIRB).

The weather conditions at the time included an air temperature of -21 °C and wind speed of 60 knots or 31 m/s (USCG, 2007a). There were also reports of precipitating ice crystals as well as a continuous blowing spray. The fact that both air temperature and wind speed recorded were well above their respective threshold's for icing coupled with reports of high winds and freezing spray are evidence that weather was the major cause of the incident.

In the case of the sinking of the HUNTER, three of the crew members (not including the master) had been found to be under the influence of illegal drugs (USCG, 2007a). The drugs, in turn, inhibited the attention and focus of the crew which brought about an argument about the proper place to take the vessel. The crew was not only unable to break off the ice, but their argument exposed the vessel to dangerous weather conditions for a prolonged period of time. This was a case where the human error factor played a major role in the incident.

It was the opinion of the experts, that the accident probably couldn't have been avoided. However, if the crew had not been under the influence of drugs, they may have been able to be more responsible, and therefore there would have been less of a chance the vessel would have had prolonged exposure to the harsh elements. It is important to note that while poor human judgment was not the cause of ice accretion on the vessel, it certainly played a major role in the vessel's demise.

4.1.4 Comparison of Cases I, II, and III

Human factors played an important role in the outcome of each of the incidents, and it was evident from issues that were revealed in the casualty reports. The owners of the LADY OF GRACE had been given specific guidelines that their vessel had to follow in order to operate safely, but in the Coast Guard's casualty report it was clear the information was either ignored or misunderstood. Because there were no survivors, there is no way to know the actual reason why the guidelines were not followed and therefore impossible to distinguish between human error and a possible lack of their understanding of the limitations of the vessel. In the case of the HUNTER, the crew was unprepared to handle the adverse conditions and was also under the influence of an illegal substance, representing two different causes for human error. The fact the STAR TREK was a 35-foot vessel operating in such conditions is evidence of a poor decision on the captain’s part as a vessel of that size is not built to be able to handle any build up of ice. However, we included the report of the STAR TREK as evidence of human error as well as in aiding us to identify contributing weather factors.

The Coast Guard realizes the weather is far mar severe in the upper Northeast Pacific which is reflected by the fact they allow for twice the amount of assumed thickness in stability testing than testing for vessels operating in the Northeast Atlantic. Therefore, the rate of accretion and amount of thickness of ice the HUNTER and the STAR TREK experienced could not be used to evaluate the thickness for the Northeast region (to be able to use the factors from these two cases in our evaluation, we would have to assume that the adequate standards for New England would be half of what they should be for the Northwest Pacific which we have no evidence of).

By reviewing these three incidents, we have identified a trend that in each case the air temperature, sea surface temperature, and wind speed were all past the threshold identified by NOAA for when icing is likely to occur. From this trend we concluded that historical weather data before and after the institution of the 1991 standards should be analyzed to help predict icing related problems.

4.2 Weather Analysis

Because we would be analyzing historical weather data and drawing conclusions on future weather conditions based on this analysis, we wanted to examine if there were any trends in sea surface temperatures. Much of our research entailed weather trends over various periods of time, and if factors such as sea surface temperature have substantially increased over time, then we would have to consider that in our analysis. In order to determine if this would be a substantial factor, we examined average monthly sea surface temperatures over the last ten years both north and south of 42° N Latitude. We plotted these data in order to identify any visible trends in sea surface temperature over time (see Figures 4-2 and 4-3).

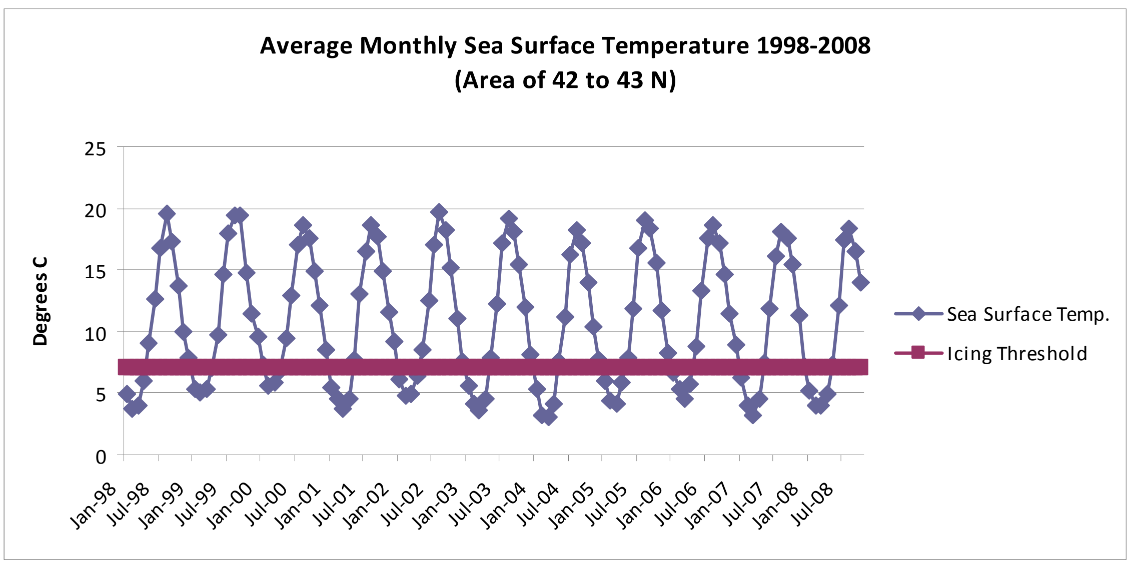

Figure 4-2: Average Monthly Sea Surface Temperature 1998-2008 between 42°N and 43°N

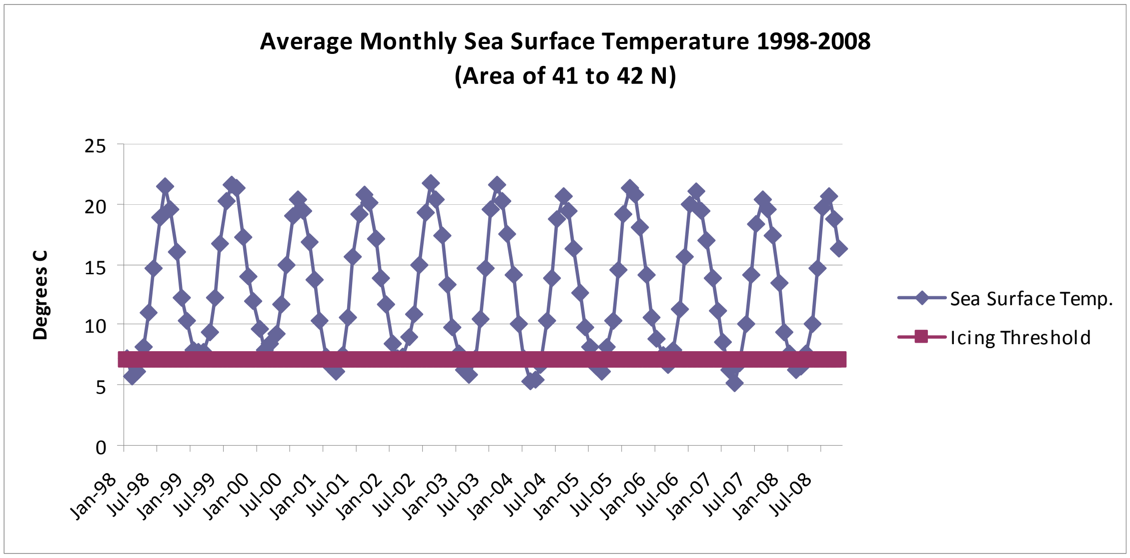

Figure 4-3: Average Monthly Sea Surface Temperature 1998-2008 between 41°N and 42°N

From these plots, there is no visible upward trend, therefore our analysis and predictions are based on relatively consistent weather trends.

4.2.1 Identifying Regions Where Icing Occurs

The first aspect of the current icing regulation we analyzed was the region in which the icing standard applies (see Appendix C). We used weather data acquired through NOAA's National Data Buoy Center. Seeing that our focus was on the northeast United States, we segmented the region into smaller zones, so that our data would be more accurate and more manageable (see Table 4-1). When numerous buoys were available in a certain region we chose those closest to fishing ports. In some cases there was only one buoy available in a region and one region, none at all.

Table 4-1: Buoy Zone Classification.

(Green denotes regions included in 1991 standards/Yellow denotes regions not included)

Zone	Latitude Range	Buoy Location	Relative Location
1	44-45°N	44.273 °N	Jonesport, ME
2	43-44°N	43.320 °N	Portland, ME
3	42-43°N	42.345 °N	Boston, MA
4	41-42°N	41.397°N	Buzzards Bay, MA
5	39-40°N	40.25°N	Long Island, NY
6	38-39°N	N/A	Not Available
7	37-38°N	38.464°N	Delaware Bay
8	36-37°N	37.5°N	North-East VA

Based on the fact that the LADY OF GRACE incident occurred below the 42° N latitude, we used zone 4 as our starting point (United States Coast Guard, 2007b). We compiled the historical data on the three weather factors that are used in icing prediction and produce an environment conducive to icing: sea surface temperature (SST), air temperature, and wind speed (see Appendix G). From these data, we plotted the average monthly extremes from 1985-2001 of these three factors along with their icing thresholds; for thresholds we used rounded figures: below 0℃ air temperature, below 7℃ water temperature, and above 9 m/s wind speed. (see Figure 4-4 and 4-5)

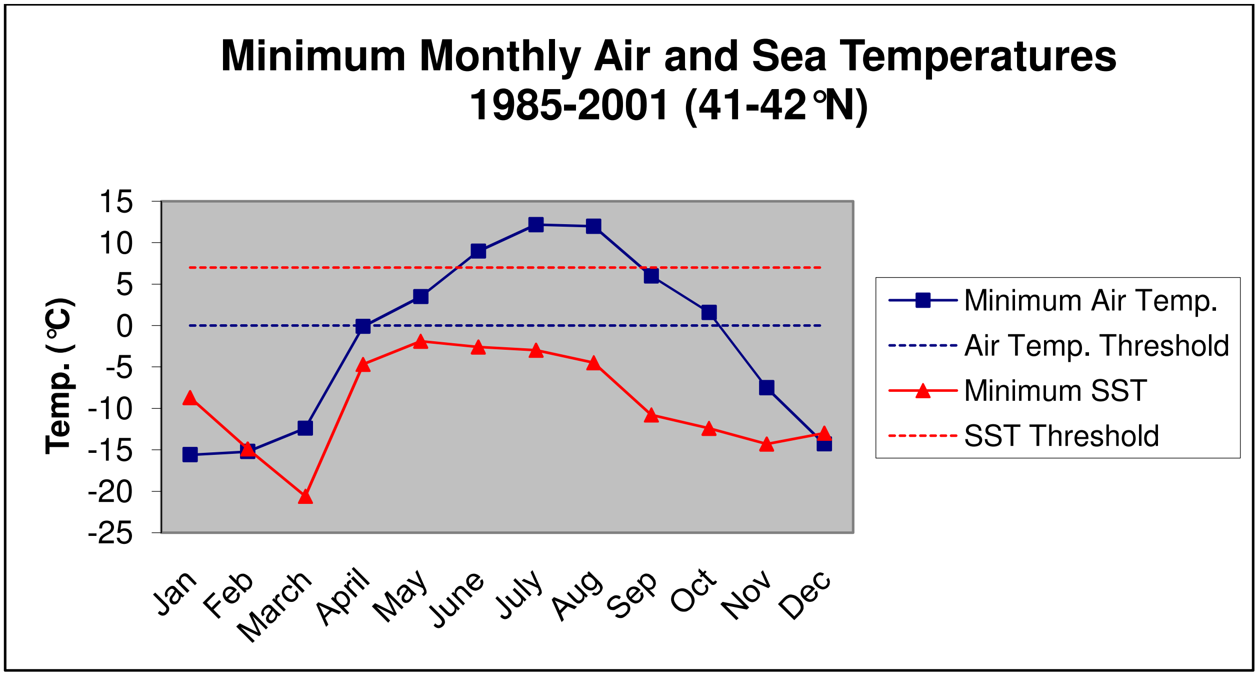

Figure 4-4: Minimum monthly air sea temperatures between 1985 and 2001.

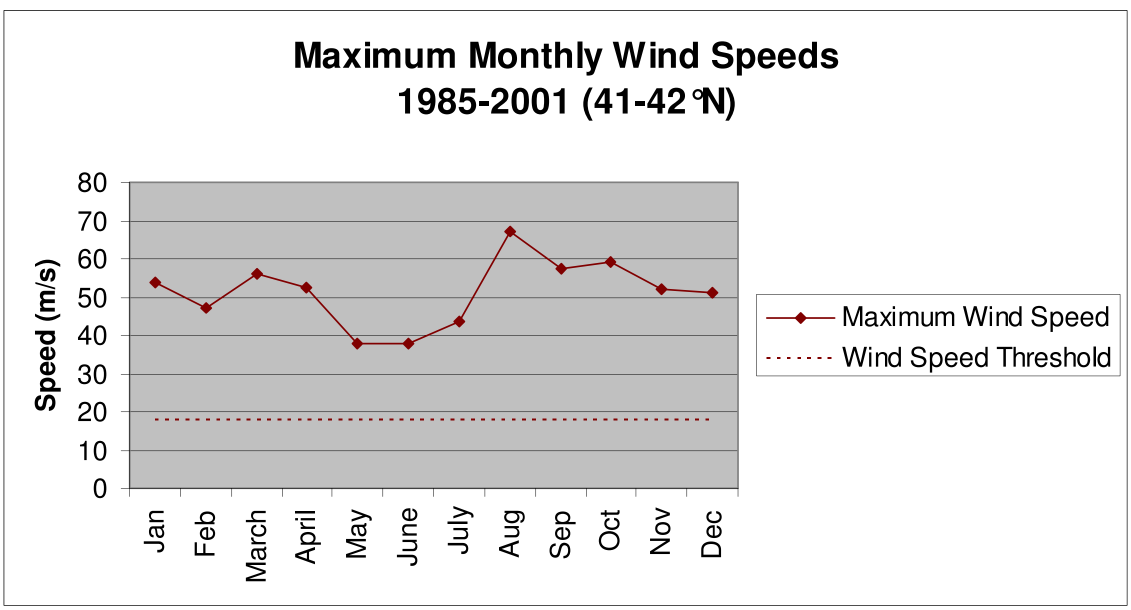

Figure 4-5: Maximum Monthly Wind Speeds between 1985 and 2001.

The plot clearly shows that there are several months where all three factors surpass their respective thresholds. This means that icing conditions were present in zone 4 during the months of December through April, and yet zone 4 is currently outside the regulated region. (for further results showing distribution see Appendix F)

In order to further identify how far south icing conditions were present, we used the National Buoy Data Center search engine to identify how often the three weather factors meet, or surpassed their icing thresholds. We examined the number of occurrences, or events, where icing conditions were present within five zones south of 42°N during the winters 1997 to 2007. Occurrences are represented in the table by events. Events are defined by NOAA as three or more hours of consecutive weather conditions (NOAA, 2008). Below is a table showing the distribution events from a buoy located in the Delaware Bay area (see table 4-2), the lowest region we found that icing is a high risk factor for marine vessels. (We found that icing does not occur south of 38°N on the east coast of the United States)

Table 4-2: Distribution of 91 Total Icing events for the winters of '97-'07.

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
'06-'07	NO EVENTS	NO EVENTS	NO EVENTS	8/42 hours	1/17 hours	NO EVENTS	9	42 hours
'05-'06	NO EVENTS	NO EVENTS	NO EVENTS	4/15 hours	1/4 hours	NO EVENTS	5	15 hours
'04-'05	NO EVENTS	NO EVENTS	7/36 hours	2/19 hours	1/8 hours	NO EVENTS	10	36 hours
'03-'04	NO EVENTS	NO EVENTS	12/44 hours	3/19 hours	NO EVENTS	NO EVENTS	15	44 hours
'02-'03	NO EVENTS	NO EVENTS	14/51 hours	4/22 hours	3/8 hours	NO EVENTS	21	52 hours
'01-'02	NO EVENTS	NO EVENTS	NO EVENT	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A
'00-'01	NO EVENTS	5/26 hours	5/19 hours	4/7 hours	1/13 hours	NO EVENTS	15	26 hours
'99-'01	NO EVENTS	NO EVENTS	6/58 hours	1/12 hours	NO EVENTS	NO EVENTS	7	58 hours
'98-'99	NO EVENTS	NO EVENTS	NO EVENTS	4/14 hours	3/17 hours	NO EVENTS	7	17 hours
'97-'98	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	2/12 hours	NO EVENTS	2	12 hours
'96-'97	NO EVENTS	NO EVENTS	NO EVENT	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A

As can be from Table 2, icing events are a common occurrence during the months of January, February, and March in Delaware Bay. The worst winter, as far as icing is concerned, experienced by the Delaware Bay region in the past ten years was 21 events in the 02'-03' winter. Delaware Bay experiences approximately eight events where the variables favoring icing are consistent for three or more hours. Although this might seem like a small number, events that are consistent for one to two hours clearly are not included in this table and still pose a high risk danger for fisherman therefore should not be forgotten.

After identifying the extent of the prevalence of icing conditions, we analyzed the severity of these conditions. In order to do so, we computed the expected icing for one of the most extreme days using the icing prediction equation for vessels heading downwind. (see Equation 1 and Table 4-3)

Equation 1: The icing predicting equation developed by James Overland in 1989

(source: Overland, 1989)

$$\mathbf{PPR} = \frac{\mathbf{V_a (T_f - T_a)}}{\mathbf{1 + 0.3(T_w - T_f)}}$$

Where:

PPR=Predicted Rate of Icing

Va = Wind Speed (m/s)

Tf = Freezing Point of Sea Water (about -1.7 °C)

Ta = Air Temperature (°C)

Tw **=** Water Temperature (°C)

Table 4-3: Data recorded from an extreme event in zone 7.

Day	Wind Speed (m/s)	Air Temp. (C)	SST (C)	PPR
2/16/2007	12.1	-5.4	4.5	46.63

The PPR for selected day was 46.63, which falls well within the category of moderate icing (see table 4-4). Therefore, vessels could experience substantial amounts icing as far south as zone 7.

Table 4-4: Icing Class and Rates

(source: NOAA, 2008)

PPR	<0	0-22.4	22.4-53.3	53.3-83.0	>83.0
Icing Class	None	Light	Moderate	Heavy	Extreme
Icing Rates (cm/hour) (inches/hour)	0	<0.7 <0.3	0.7-2.0 0.3-0.8	2.0-4.0 0.8-1.6	>4.0 >1.6

4.2.2 Time Period Analysis

The second aspect of the current icing regulations we analyzed was the regulated time frame within which the icing standard applies. Much like the regional analysis we completed, we utilized the "events" history for each region. Looking at zones 1, 2 and 3, which are currently in the 1991 icing regulations, we analyzed where the time of the year where icing events usually tended to begin and then dissipate. We were only able to develop tables for two of the three zones (Boston and Portland) as ten year historical data were not available for Jonesport, ME (see Table 4-5 and 4-6). For a full results including distribution table and breakdown see Appendix B.

Table 4-5: Distribution of 287 total icing events for the winters of '97-'07

(Boston, MA)

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
'06-'07	NO EVENTS	NO EVENTS	9/33 hours	19/23 hours	7/21 hours	2/9 hours	37	33 hours
'05-'06	NO EVENTS	5/18 hours	5/32 hours	10/38 hours	7/35 hours	NO EVENTS	27	38 hours
'04-'05	NO EVENTS	3/34 hours	12/34 hours	10/14 hours	4/23 hours	NO EVENTS	29	34 hours
'03-'04	NO EVENTS	3/9 hours	15/53 hours	5/29 hours	3/30 hours	1/4 hours	27	53 hours
'02-'03	NO EVENTS	3/11 hours	16/42 hours	16/35 hours	6/19 hours	1/6 hours	42	42 hours
'01-'02	NO EVENTS	1/15 hours	5/16 hours	5/18 hours	3/32 hours	NO EVENTS	14	32 hours
'00-'01	NO EVENTS	5/99 hours	6/18 hours	5/33 hours	5/22 hours	NO EVENTS	21	99 hours
'99-'01	NO EVENTS	3/26 hours	8/57 hours	11/20 hours	1/27 hours	NO EVENTS	23	57 hours
'98-'99	NO EVENTS	2/16 hours	11/33 hours	6/16 hours	5/43 hours	NO EVENTS	24	43 hours
'97-'98	NO EVENTS	2/8 hours	5/15 hours	2/15 hours	3/24 hours	NO EVENTS	12	24 hours
'96-'97	NO EVENTS	1/5 hours	14/46 hours	5/11 hours	8/15 hours	3/15 hours	31	46 hours

Table 4-6: Distribution of 259 total icing events for the winters of '97-'07

(Portland, ME)

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
'06-'07	NO EVENTS	NO EVENTS	7/13 hours	13/35 hours	8/16 hours	2/7 hours	30	35 hours
'05-'06	NO EVENTS	5/16 hours	6/37 hours	15/32 hours	3/5 hours	NO EVENTS	29	37 hours
'04-'05	NO EVENTS	6/41 hours	8/32 hours	NO EVENTS	NO EVENTS	NO EVENTS	14	41 hours
'03-'04	NO EVENTS	2/28 hours	13/22 hours	6/14 hours	4/16 hours	1/5 hours	26	28 hours
'02-'03	NO EVENTS	2/20 hours	22/34 hours	13/23 hours	10/11 hrs.	1/4 hours	48	34 hours
'01-'02	NO EVENTS	1/9 hours	5/13 hours	8/11 hours	5/19 hours	NO EVENTS	19	19 hours
'00-'01	NO EVENTS	4/11 hours	5/12 hours	8/21 hours	3/35 hours	NO EVENTS	20	35 hours
'99-'01	NO EVENTS	2/6 hours	11/38 hours	7/18 hours	1/28 hours	NO EVENTS	21	38 hours
'98-'99	NO EVENTS	8/37 hours	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	8	37 hours
'97-'98	NO EVENTS	5/10 hours	4/28 hours	5/17 hours	NO EVENTS	NO EVENTS	14	28 hours
'96-'97	NO EVENTS	3/13 hours	13/29 hours	5/11 hours	7/7 hours	2/10 hours	30	29 hours

As can be seen from these two tables, the regions currently included in the 1991 icing regulations never experience icing events before December and after April. Further looking at the events that occurred in April in the Boston and Portland region, there was never an event in April that occurred after April 15.

Considering the Coast Guard might change their regulations to include more southern regions that may not have as severe winters as those in the far north we compared the distribution of events for two regions north and south of 42°N latitude.

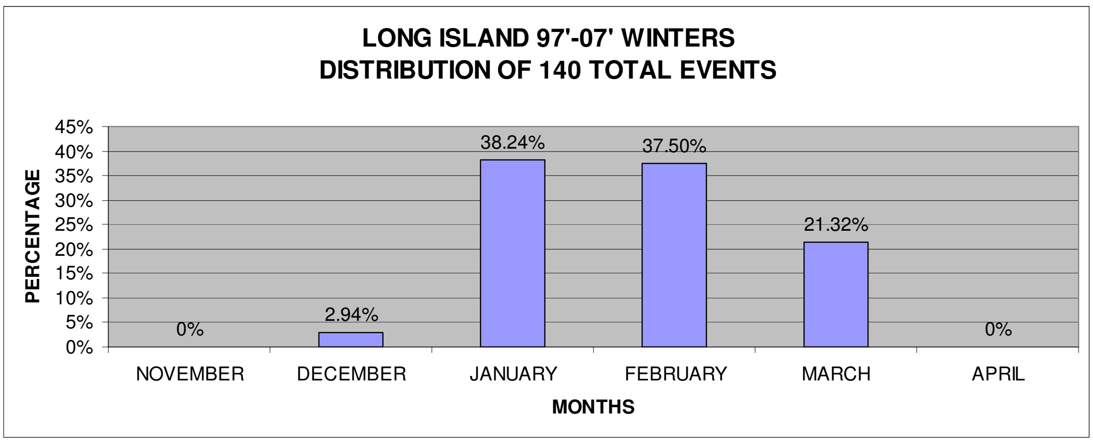

Figure 4-6: **Distribution of icing events for Long Island.**

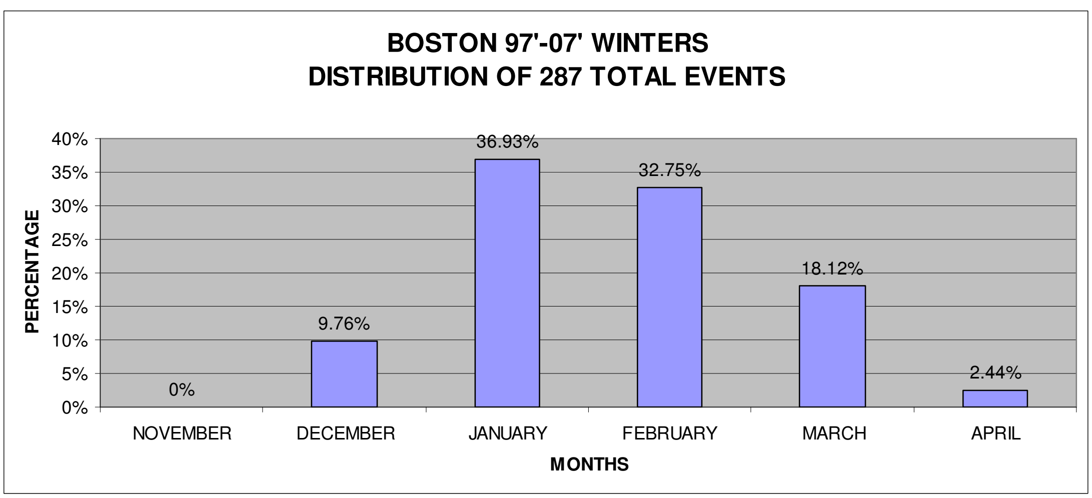

Figure 4-7: Distribution of icing events for Boston.

As can be seen in the above figures while there is a vast difference in the number of events between the two regions the event distribution for Boston and Long Island are very similar, however looking at the distribution for Delaware Bay it can be seen that the majority of the events occur during the months of January and February at a far less frequency. (see figure 4-8)

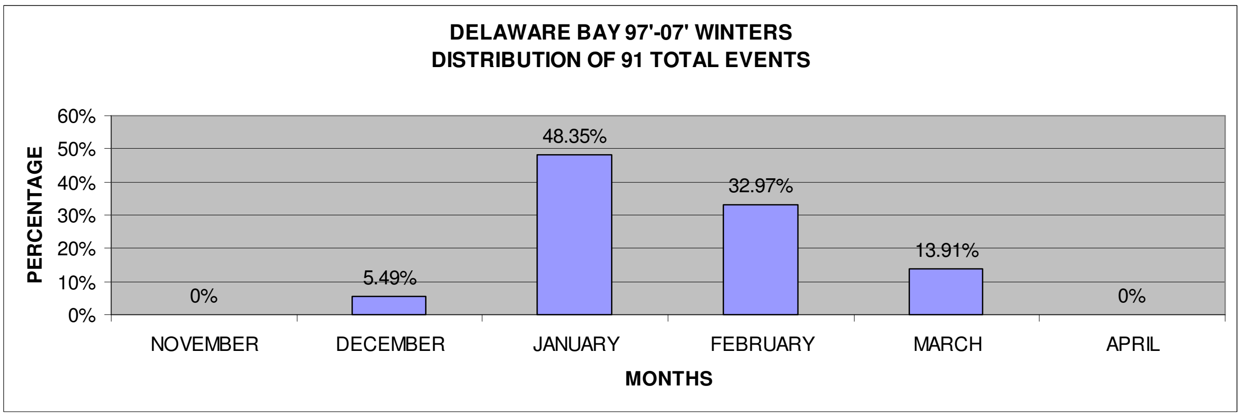

Figure 4-8: Distribution of icing events for Delaware Bay.

Appendix B contains the full distribution table and breakdown for the five buoys we completed the ten year analysis on.

4.3 1991 Stability Analysis Criteria

In stability testing, the engineer applies a uniform distribution of 0.325 inches of ice across the vertical surface of a vessel and 3.07 inches of ice across the horizontal surface; the vessel with these loading must maintain stability in order to pass the Coast Guard's 1991 icing regulations (Jon Womack, personal communication, December 12, 2008). We were unable to collect any technical data that would allow us to evaluate the thickness on a quantitative level.

However, from past case incidents and interviews with experts in the fields of Naval Architecture, we were able to produce some qualitative results.

4.3.1 Marine Safety Center Analysis

According to the author of the LADY OF GRACE stability analysis report, LCDR Robert Compher, an officer of the Marine Safety Center, the assumed thickness of ice cited in the 1991 Coast Guard standards needs to be reviewed, due to the fact that his analysis of the incident showed the vessel was likely taking on 0.75 inches or more of ice build-up per hour (Compher, 2007). Compher's computer aided analysis of the vessel's structure showed that once approximately 2.25 inches of ice was uniformly distributed across the surface of the vessel, it would capsize. More specifically Compher applied 0.325 inches of ice across the hull, deck, and super structure of the vessel, which is different from the specific Coast Guard regulations (see Appendix C). For the railings and riggings he only applied ice to the top half, which he believed was more realistic.

One factor that showed a weakness in the current standard, was how there is no regulation for how thorough the stability analyses have to be carried out by the Naval Architect, Thomas M. Farrell Naval Architects, Inc. (Compher, 2007). Comparing the model that that Naval Architect made for the LADY OF GRACE to that of the post-incident stability analysis showed a major difference in detail. While the model created by the independent firm showed two main parts representing the LADY OF GRACE, Compher's model was much more detailed with full riggings and railings shown (see figure 4-9 and 4-10).

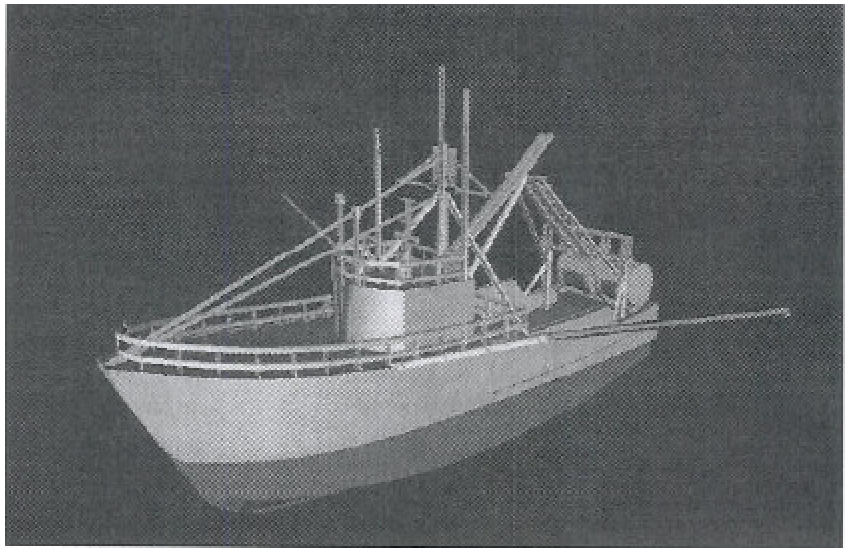

Figure 4-9: LCDR Compher's model of the LADY OF GRACE.

(source: Compher, 2007)

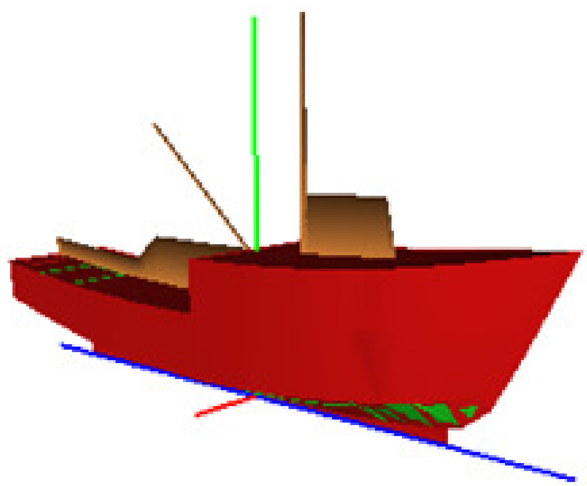

Figure 4-10: Thomas M. Farrel Naval Architecture Inc.'s model of the LADY OF GRACE.

(source: Compher, 2007)

As can be seen from a comparison of these two models, the one generated by Compher is far more detailed and therefore more accurate. Compher's model also took eight times the amount of hours to complete then the other model (LCDR Robert Compher, personal communication, December 18, 2008). Because the Coast Guard has no requirement for the thoroughness of the stability analysis the owners of the LADY OF GRACE received a far less accurate report. This is an area where the economic factor comes into play. A more detailed report has a higher cost, and in an industry like Commercial Fishing, the fishermen are willing to take the risk to save costs.

4.3.2 Past Incidents

We were unable to find any incidents that involved a vessel over 79 feet and therefore analyzed those above 50 feet because of the fact the Coast Guard is currently expanding their regulations to include all vessels over 50 feet. Assuming the Coast Guard would use a similar mark in their newer standards, we used incidents that involved vessels above 50 feet. In all three incidents the rate of accretion was at least at a rate of 0-0.3 inches/hour. Comparing this to the current assumed thickness, crews would have to be able to keep up with the removal of ice every half hour which would be unlikely to happen (LCDR Robert Compher, personal communication, December 12, 2008). Fishing vessel crew members who choose to voyage out into conditions that favor ice accretion would not likely do so planning on keeping up with the removal of ice every half hour.

4.3.3 Independent Naval Architect Analysis

Some of the commercial fishing vessels that are currently operating in the cold climate regions of the east coast of the United States were manufactured in the south and were converted over to be able to operate as scalloping and clamming vessels. We were able to meet with a Mr. Jon Womack, who works for a naval architecture firm located in Maryland and found out further information on these vessels. The vessels that he analyzes are 80-120 feet vessels that have been converted to be able operate as Mid-Atlantic clamming and fishing vessels. The majority are not able to maintain stability when tested with the current assumed thickness of ice and are not permitted to be operating in the current restricted time period and region (Jon Womack, personal communication, December 12, 2008). Also because of environmental regulations pertaining to permitted areas where vessels are allowed to harvest marine life, over the years the region has been gradually moving north up the east coast and therefore into colder waters. It was noted by Mr. Womack that perhaps the stability testing be altered from a uniform distribution method to a forward half distribution, which is more realistic and comparable to actual incidents and reports.

4.4 Coast Guard Communication with Commercial Fishermen

We looked at the current methods the Coast Guard uses (outside of its 1991 icing regulations) to attempt and lower the risk of an incident occurring due to icing. Through various media, they publicize the problems and severity of the accumulation of ice. Although there are currently no seminars that are mainly focused on the issue of icing and commercial fishing vessels, it has been included in training sessions sponsored by the Coast Guard. After incidents such as the tragedy of the NORTHERN EDGE, a commercial fishing vessel that sank in 2004 off the coast of Nantucket, MA, safety awareness among fisherman was brought into question by fisherman in the surrounding communities. Subsequently the Coast Guard sponsored numerous training sessions in which they sent safety officials, such as Kevin Coyle, who is regarded as one of the best safety examiners in the field of commercial fishing safety (Ted Harrington, personal communication, December 12, 2008). The fishing vessel safety division of the Coast Guard issue flyers that indicate the weather factors that are main contributors to the accretions of ice, as well as a breakdown of the effects on stability (Jack Kemerer, personal communication, December 12, 2008). They also write articles in various fishing periodicals and magazines that spread the awareness of issues commercial fishermen might face on the water.

4.5 Summary

Over the duration of this project we indentified numerous contributing factors to the effects of icing on commercial fishing vessels. We discovered trends in the weather factors present in past incidents as well as in the humans factors involved. By collecting and graphing archival weather data we were also able to identify regions and time periods where marine vessel icing is a prevalent issue. We reviewed the stability analysis criteria, as well as gain expert opinions in the field of naval architecture. Finally, by reviewing the current methods the Coast Guard uses for spreading awareness of the issue of icing. From these results we were able to confidently make conclusions and recommendations on the adequacy of the 1991 icing standards.

5 Conclusions and Recommendations

Commercial fishing in cold climate regions will always pose a higher risk regardless of the number of regulations imposed by the Coast Guard. Through various types of data analysis, we found reason to questions in the 1991 Coast Guard icing standards. If changed, they could lower the risk of a vessel accident due to icing. Focusing on the three main aspects of the 1991 standards: time frame, region, and stability analysis of ice, as well as the Coast Guards methods for spreading awareness of the issue of icing, we have developed a useful tool possibly preventing incidents like the LADY OF GRACE from occurring in the future.

The first conclusion we made was pertaining to the current time period (Nov. 15 to April 15), which the Coast Guard uses in its 1991 regulations. Looking at a monthly scale, historical averages showed trends of probable icing from the month of November to the month of April. Furthermore, by evaluation of the events where conditions that favor icing are consistent for at least three hours, we were able to see that over the past ten years icing was never an issue outside November 15 and April 15. **We therefore concluded that the current timeframe is adequate and requires no adjustment. However, the Coast Guard should look into a shortened time period for fishing regions south of 42°N, as icing is not a problem as long of a time period as it is in the region north of 42°N.** (Note: Although the results showed that icing was never likely to occur in the month of November, the Coast Guard would only make adjustments to expand the time period and not shorten it).

The second conclusion that we made pertained to the region the Coast Guard uses in the 1991 icing standards. Currently in the New England region, the Coast Guard's regulations only pertain to vessels traveling north of 42°N latitude. Utilizing the three main weather factors NOAA uses to predict when icing is most likely to occur, we were able to determine when an event that would likely involve the accretion of ice at a light to moderate level would occur. We found that icing occurrence was probable as low as the 38°N parallel. As we went further south, the time in which icing was likely to be an issue for vessels shortened from November to April to January to February. **We conclude from these results that the region defined in the 1991 standards is inadequate and we recommend the Coast Guard expand their regulations to include vessels traveling north of 38°N.**

The final aspect of the 1991 icing standards that we analyzed involved the stability criteria in theoretical testing. We were unable to produce any technical evidence to dispute the current assumed thickness or were unable to find any incidents involving vessels of 79 feet, however seeing as though the Coast Guard is currently expanding its standards to include all vessels over 50 feet, by looking at the LADY OF GRACE incident which was between 50-79 feet, as well as from speaking with experts in the field of naval architecture, the general consensus was that the mark be further reviewed. **We could make no concrete conclusion on the assumed thickness and but recommend that the Coast Guard further research the adequacy of the current assumed thickness for all vessels of 50 feet. However, we did conclude that the uniform distribution method listed in the 1991 regulations is inadequate as it is not comparable to the amount of accretion as well as area as to where vessels experience icing in realistic scenarios and recommend the Coast Guard look into requiring different methods such as a forward half distribution of ice.**

Although the Coast Guard is currently working on regulations to include all vessels over 50 feet, human factors can never be overlooked. There were various precautions that could have been taken before the incident of the LADY OF GRACE, which merely involved following specific recommendations from a naval architect. Although the LADY OF GRACE probably would still have capsized due to the extreme conditions it was encountering, the lives of the four crew members who perished might have been saved had the survival equipment not been encased in ice and all the crew completed safety survival training. Whether it is the main cause of the incident and the reason for various other outcomes or not, human responsibility can never be ignored. Based on the various media which the Coast Guard uses to create awareness of the issue of icing and training seminars, **we conclude the Coast Guard is doing an adequate job educated fishermen on the effects of icing. However, due to the fact that our recommendations call for the regulations to be expanded in an area previously not required to pass stability testing, that the Coast Guard expand their educational programs to the relevant fishing ports.**

In summary, the 1991 icing standards have some inadequacies, and we recommend the Coast Guard make some adjustments to in order to lower the risk of an incident occurring due to icing. By expanding the region of concern for icing problems this will lower the risk of an incident occurring below of 42°N latitude. Also through further research into the stability criteria currently listed in the regulations, a more accurate assumed thickness and method of distribution could also lower the risk of vessels capsizing due to icing. Since the Coast Guard cannot prevent a vessel from voyaging out into harsh weather conditions, in end the responsibility falls on the fishermen themselves to maintain safety on their vessels.

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Appendix A – USCG Mission Statement

The United States Coast Guard was established on August 4th, 1790 (United States Coast Guard, 2008a). Congress authorized the construction of ten vessels to enforce trade and tariff laws, as well as to monitor smuggling. In its early years, the USCG was known as the Revenue Marine and the Revenue Cutter Service. It wasn't always in the "Life Saving Business". The unit that was dedicated to saving lives and the enforcement of maritime law before 1915 was simply known as the Life-Saving Service. In that year the two services merged, and that marked the birth of the service's current title. Although its purpose and name has changed since its conception, its principles have remained the same.

The Coast Guard consists of approximately 40,000 active men and women stationed all over the country (United States Coast Guard, 2008a). A 2008 report published by the USCG, reported an estimated a 5.8 billion dollar budget, spread over numerous planned projects and sub-divisions. As of 2008, the Coast Guard has organized its purpose into three main categories: safety, security, and stewardship (United States Coast Guard, 2007d). These categories are broken down as can be seen in Table 0.1.

The Coast Guard, like other armed services in America, has a hierarchal structure. At the top of the chain of command is the Commandant (United States Coast Guard, 2008c). The Commandant of the USCG, Admiral Thad W. Allen, made the following statement pertaining to the Coast Guard's constantly evolving role in serving the American public (United States Coast Guard, 2007d):

> As we adapt to meet new mission requirements we will retain our organizational character as military, multi-mission, maritime service. Our core values, principles of operation and leadership competencies-together with a bias for action remains fundamental to our success. This character has been tested from the rooftops of New Orleans to the oil platforms of the Persian Gulf. It sustains us. (p. 2)

The United States Coast Guard realizes the importance of their role in society requires them to constantly evolve and adapt to every new situation that they face. Through numerous division, the thousands that make up the Coast Guard all work bettering various aspects of coastal and ocean responsibility. From environmental protection to maritime law enforcement, every day they strive to serve society to the best of their ability.

Table 0-1: United States Coast Guard Division Breakdown.

(Source: United States Coast Guard, 2007d, p. 2)

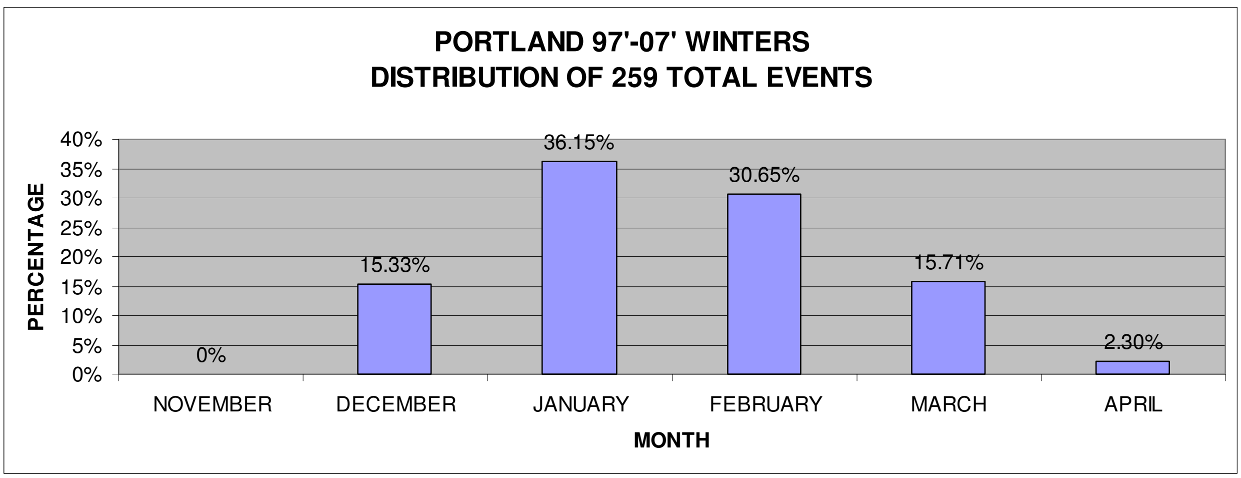
Safety	Security	Stewardship
Search and Rescue	Ports, Waterways, & Coastal Security	Marine Environmental Protection
Marine Safety	Illegal Drug Interdiction	Living Marine Resources
	Undocumented Migrant Interdiction	Aids to Navigation
	Defense Readiness	Ice Operations
	Other Law Enforcement	

Appendix B – Full Distribution of Icing Events

Contained in pages 62-66 are the full results of the distribution of icing event during the past eleven inters for Portland, ME, Boston, MA, Buzzards Bay, Long Island, and Delaware Bay (NOAA, 2008). For each region there is a main table that correlates winters to number of events, the most severe (longest duration) event that month, the total number of events that winter, and the most severe event that winter. There is also a bar graph containing the distribution for each month over the past eleven winters. The third aspect of the results is a table that displays the breakdown by total events and percentage for each month. These results played a major role in the outcome of our conclusions and recommendations.

DISTRIBUTION OF ICING EVENTS FOR WINTERS 1997-2007
PORTLAND, ME – 43.531°N

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
'06-'07	NO EVENTS	NO EVENTS	7/13 hours	13/35 hours	8/16 hours	2/7 hours	30	35 hours
'05-'06	NO EVENTS	5/16 hours	6/37 hours	15/32 hours	3/5 hours	NO EVENTS	29	37 hours
'04-'05	NO EVENTS	6/41 hours	8/32 hours	NO EVENTS	NO EVENTS	NO EVENTS	14	41 hours
'03-'04	NO EVENTS	2/28 hours	13/22 hours	6/14 hours	4/16 hours	1/5 hours	26	28 hours
'02-'03	NO EVENTS	2/20 hours	22/34 hours	13/23 hours	10/11 hrs.	1/4 hours	48	34 hours
'01-'02	NO EVENTS	1/9 hours	5/13 hours	8/11 hours	5/19 hours	NO EVENTS	19	19 hours
'00-'01	NO EVENTS	4/11 hours	5/12 hours	8/21 hours	3/35 hours	NO EVENTS	20	35 hours
'99-'01	NO EVENTS	2/6 hours	11/38 hours	7/18 hours	1/28 hours	NO EVENTS	21	38 hours
'98-'99	NO EVENTS	8/37 hours	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	8	37 hours
'97-'98	NO EVENTS	5/10 hours	4/28 hours	5/17 hours	NO EVENTS	NO EVENTS	14	28 hours
'96-'97	NO EVENTS	3/13 hours	13/29 hours	5/11 hours	7/7 hours	2/10 hours	30	29 hours

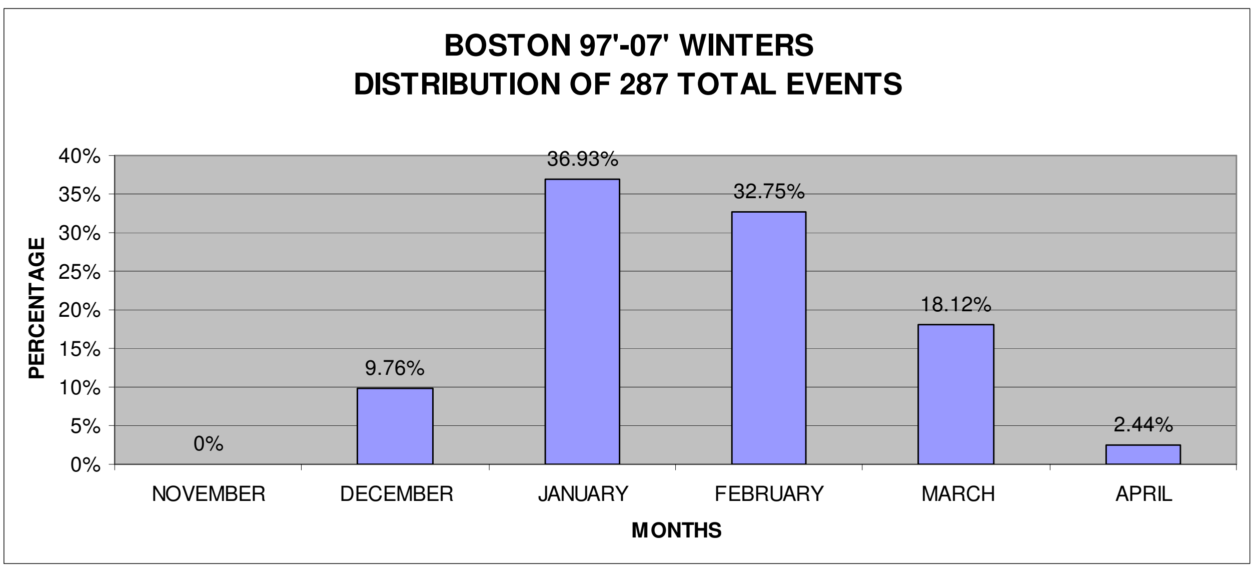


DISTRIBUTION

MONTH	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
PERCENT	0%	15.33%	36.15%	30.65%	15.71%	2.30%
TOTAL	0	38	94	80	41	6

DISTRIBUTION OF ICING EVENTS FOR WINTERS 1997-2007
BOSTON, MA – 42.354°N

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
'06-'07	NO EVENTS	NO EVENTS	9/33 hours	19/23 hours	7/21 hours	2/9 hours	37	33 hours
'05-'06	NO EVENTS	5/18 hours	5/32 hours	10/38 hours	7/35 hours	NO EVENTS	27	38 hours
'04-'05	NO EVENTS	3/34 hours	12/34 hours	10/14 hours	4/23 hours	NO EVENTS	29	34 hours
'03-'04	NO EVENTS	3/9 hours	15/53 hours	5/29 hours	3/30 hours	1/4 hours	27	53 hours
'02-'03	NO EVENTS	3/11 hours	16/42 hours	16/35 hours	6/19 hours	1/6 hours	42	42 hours
'01-'02	NO EVENTS	1/15 hours	5/16 hours	5/18 hours	3/32 hours	NO EVENTS	14	32 hours
'00-'01	NO EVENTS	5/99 hours	6/18 hours	5/33 hours	5/22 hours	NO EVENTS	21	99 hours
'99-'01	NO EVENTS	3/26 hours	8/57 hours	11/20 hours	1/27 hours	NO EVENTS	23	57 hours
'98-'99	NO EVENTS	2/16 hours	11/33 hours	6/16 hours	5/43 hours	NO EVENTS	24	43 hours
'97-'98	NO EVENTS	2/8 hours	5/15 hours	2/15 hours	3/24 hours	NO EVENTS	12	24 hours
'96-'97	NO EVENTS	1/5 hours	14/46 hours	5/11 hours	8/15 hours	3/15 hours	31	46 hours

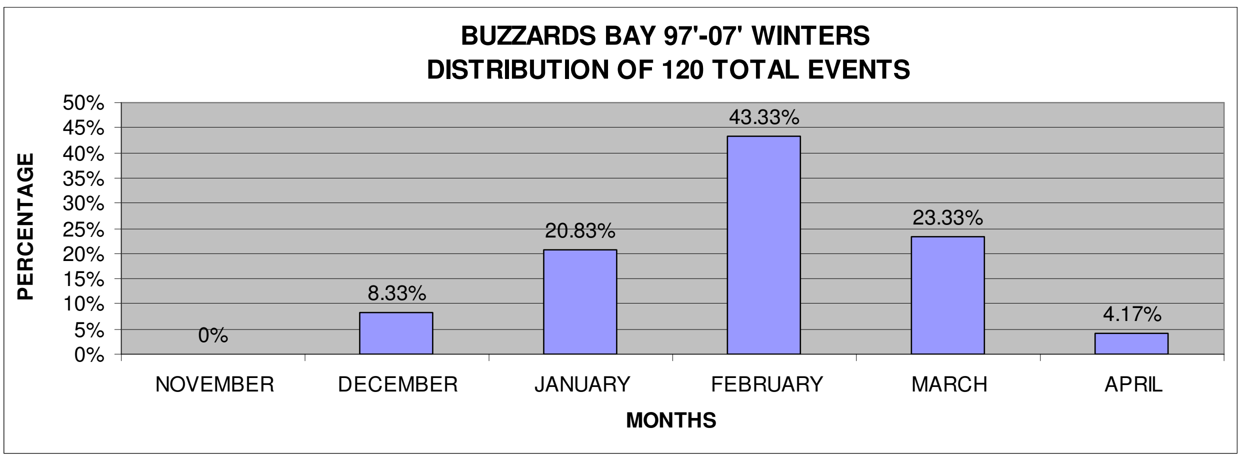


DISTRIBUTION

MONTH	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
PERCENT	0%	9.76%	36.93%	32.75%	18.12%	2.44%
TOTAL	0	28	106	94	52	7

DISTRIBUTION OF ICING EVENTS FOR WINTERS 1997-2007
BUZZARDS BAY – 41.397°N

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
‘06-‘07	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	2/7 hours	2	20 hours
‘05-‘06	NO EVENTS	4/17 hours	3/42 hours	13/27 hours	5/24 hours	NO EVENTS	25	42 hours
‘04-‘05	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A
‘03-‘04	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A
‘02-‘03	NO EVENTS	3/13 hours	16/88 hours	19/29 hours	7/19 hours	1/5 hours	46	88 hours
‘01-‘02	NO EVENTS	1/8 hours	3/16 hours	8/19 hours	5/19 hours	1/4 hours	18	19 hours
‘00-‘01	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A
‘99-‘01	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A
‘98-‘99	NO EVENTS	NO EVENTS	NO EVENTS	6/29 hours	5/41 hours	NO EVENTS	11	41 hours
‘97-‘98	NO EVENTS	2/5 hours	3/7 hours	3/9 hours	NO EVENTS	NO EVENTS	8	9 hours
‘96-‘97	NO EVENTS	NO EVENTS	NO EVENTS	3/15 hours	6/13 hours	1/9 hours	10	15 hours

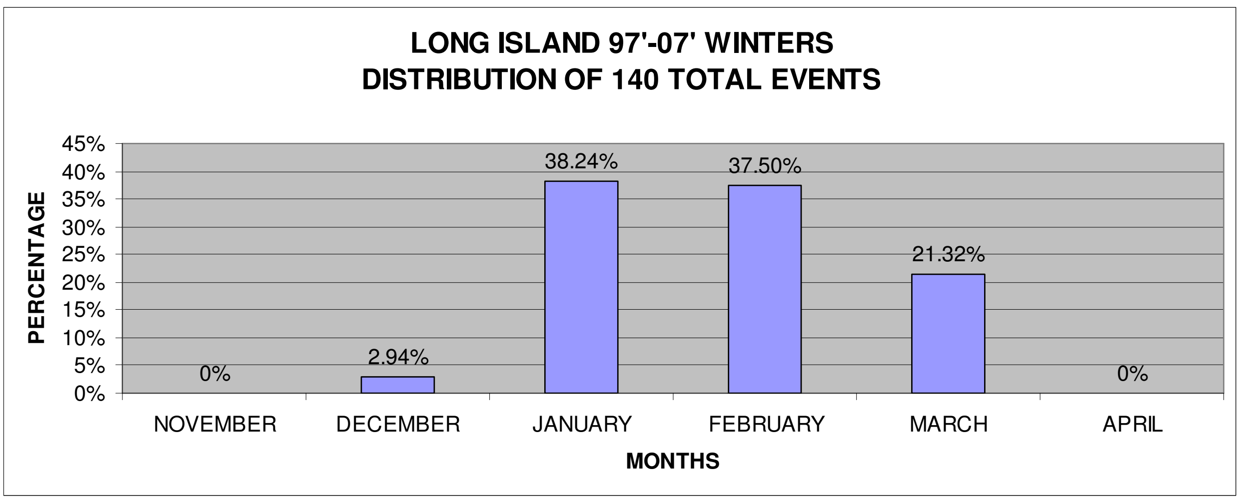


DISTRIBUTION

MONTH	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
PERCENT	0%	8.33%	20.83%	43.33%	23.33%	4.17%
TOTAL	0	10	25	52	28	5

DISTRIBUTION OF ICING EVENTS FOR WINTERS 1997-2007
LONG ISLAND, NY – 40.250°N

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
'06-'07	NO EVENT	NO EVENT	NO EVENT	10/47 hours	2/27 hours	NO EVENT	12	47 hours
'05-'06	NO EVENT	NO EVENT	1/8 hours	7/44 hours	3/16 hours	NO EVENT	11	44 hours
'04-'05	NO EVENT	NO EVENT	8/43 hours	2/26 hours	2/14 hours	NO EVENT	12	43 hours
'03-'04	NO EVENT	NO EVENT	13/66 hours	4/19 hours	1/11 hours	NO EVENT	18	66 hours
'02-'03	NO EVENT	NO EVENT	9/76 hours	11/51 hours	6/11 hours	NO EVENT	26	76 hours
'01-'02	NO EVENT	NO EVENT	NO EVENT	1/7 hours	3/17 hours	NO EVENT	4	17 hours
'00-'01	NO EVENT	4/43 hours	6/20 hours	5/22 hours	2/15 hours	NO EVENT	17	43 hours
'99-'01	NO EVENT	NO EVENT	6/35 hours	2/15 hours	1/9 hours	NO EVENT	13	35 hours
'98-'99	NO EVENT	NO EVENT	1/11 hours	5/13 hours	5/27 hours	NO EVENT	11	27 hours
'97-'98	NO EVENT	NO EVENT	NO EVENT	NO EVENT	1/40 hours	NO EVENT	1	40 hours
'96-'97	NO EVENT	NO EVENT	8/32 hours	4/5 hours	3/7 hours	NO EVENT	15	32 hours

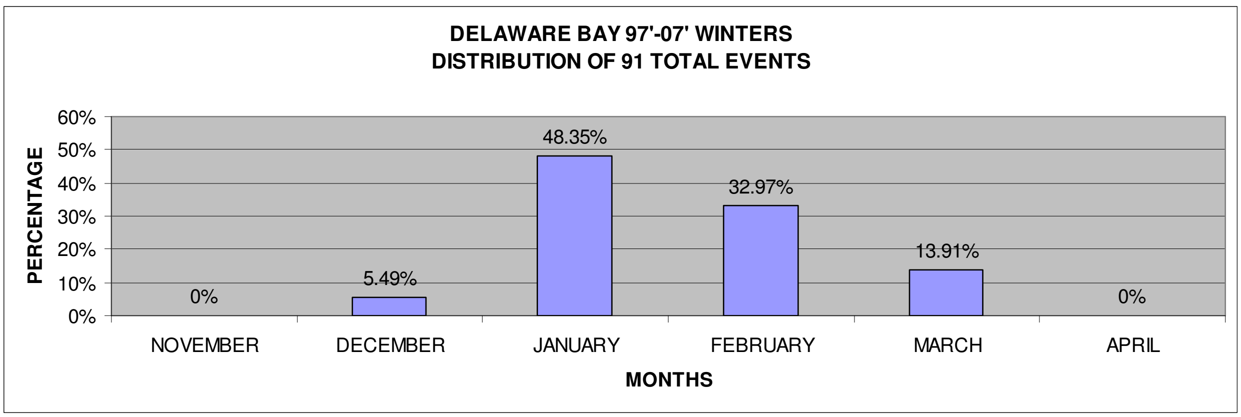


DISTRIBUTION

MONTH	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
PERCENT	0%	2.94%	38.24%	37.50%	21.32%	0%
TOTAL	0	4	52	51	29	0

DISTRIBUTION OF ICING EVENTS FOR WINTERS 1997-2007
DELAWARE BAY – 38.464°N

WINTER	NOVEMBER (#/max)	December (#/max)	January (# /max)	February (#/max)	March (#/max)	April (#/max)	Total Events	Most Severe
'06-'07	NO EVENTS	NO EVENTS	NO EVENTS	8/42 hours	1/17 hours	NO EVENTS	9	42 hours
'05-'06	NO EVENTS	NO EVENTS	NO EVENTS	4/15 hours	1/4 hours	NO EVENTS	5	15 hours
'04-'05	NO EVENTS	NO EVENTS	7/36 hours	2/19 hours	1/8 hours	NO EVENTS	10	36 hours
'03-'04	NO EVENTS	NO EVENTS	12/44 hours	3/19 hours	NO EVENTS	NO EVENTS	15	44 hours
'02-'03	NO EVENTS	NO EVENTS	14/51 hours	4/22 hours	3/8 hours	NO EVENTS	21	52 hours
'01-'02	NO EVENTS	NO EVENTS	NO EVENT	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A
'00-'01	NO EVENTS	5/26 hours	5/19 hours	4/7 hours	1/13 hours	NO EVENTS	15	26 hours
'99-'01	NO EVENTS	NO EVENTS	6/58 hours	1/12 hours	NO EVENTS	NO EVENTS	7	58 hours
'98-'99	NO EVENTS	NO EVENTS	NO EVENTS	4/14 hours	3/17 hours	NO EVENTS	7	17 hours
'97-'98	NO EVENTS	NO EVENTS	NO EVENTS	NO EVENTS	2/12 hours	NO EVENTS	2	12 hours
'96-'97	NO EVENTS	NO EVENTS	NO EVENT	NO EVENTS	NO EVENTS	NO EVENTS	N/A	N/A



DISTRIBUTION

MONTH	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
PERCENT	0%	5.49%	48.35%	32.97%	13.91%	0%
TOTAL	0	5	44	30	12	0%

Appendix C – Current USCG Icing Regulations

(Source: United States Coast Guard, 1991)

§ 28.500 Applicability.

This subpart applies to each commercial fishing industry vessel which is 79 feet (24 meters) or more in length.

§ 28.550 Icing.

(a) *Applicability.* Each vessel that operates north of 42° North latitude between November 15 and April 15 or south of 42° South latitude between April 15 and November 15 must meet the requirements of this section.

(b) Except as provided in paragraph (d) of this section, the weight of assumed ice on each surface above the waterline of a vessel which operates north of 66°30' North latitude or south of 66° South latitude must be assumed to be at least:

(1) 6.14 pounds per square foot (30 Kilograms per square meter) of horizontal projected area which corresponds to a thickness of 1.3 inches (33 millimeters); and

(2) 3.07 pounds per square foot (15 Kilograms per square meter) of vertical projected area which corresponds to a thickness of 0.65 inches (16.5 millimeters).

(c) Except as provided in paragraph (d) of this section, the weight of assumed ice on a vessel that operates north of 42° North but south of 66°30' North latitude or south of 42°South but north of 66° South latitude must be assumed to be at least one-half of the values required by paragraphs (b) (1) and (b) (2) of this section.

(d) The height of the center of gravity of the accumulated ice should be calculated according to the position of each corresponding horizontal surface (deck and gangway) and each other continuous surface on which ice can reasonably be expected to accumulate. The projected horizontal and vertical area of each small discontinuous surface such as a rail, a spar, and rigging with no sail can be accounted for by increasing the calculated area by 15 percent.

(e) The weight and location of ice must be included in the vessel's weight and centers of gravity in each condition of loading when performing the stability calculations required by this subpart.

[CGD 88–079, 56 FR 40393, Aug. 14, 1991; 56 FR 47679, Sept. 20, 1991]

Appendix D - Glossary of Stability Terms

Broach or Broaching – The loss of control of a vessel's direction when the vessel's bow is buried in a wave and the stern is forced around by the following wave.

Buoyancy – The forces acting to push the vessel up in the water.

Capsizing Moment – The moment or torque created by a negative righting arm multiplied by the vessel's displacement (weight) that is acting to capsize the vessel.

Cargo – All of the fish caught as well as any ice, salt, or packaging carried to preserve the catch.

Center of Buoyancy – The submerged geometric center of watertight volume of a vessel at a given heel angle.

Center of Gravity – The point where the combined weight of the vessel can be considered concentrated acting to pull down the vessel.

Draft – The vertical distance between the waterline and the bottom of the keel.

Freeboard – The vertical distance between the waterline and the highest watertight deck.

Free Surface – The motion of liquids in slack tanks, fish holds, or bilges.

Gravity – The forces acting to pull the vessel down in the water.

Heeling – The side to side rolling of the vessel.

Hull – The enclosed portions of the vessel below the highest watertight deck that runs continuously from the bow to the stern.

Inclining Experiment – Procedure used to determine a vessel's lightship characteristics (weight, longitudinal center of gravity, and vertical center of gravity) used in all stability calculations.\

Initial Stability – The stability felt by the crew during operations in relatively calm seas, which for typical fishing vessels is limited to 10-20 degrees of heel from the initial upright position.

List – A permanent heel angle that occurs when the vessel is not loaded evenly port and starboard or a weight is being lifted over the vessel's side.

Loll – A temporary heel angle that occurs from free surface effects or lifting weights.

Negative Stability – The combination of the center of gravity and the center of buoyancy creates a capsizing action that forces the vessel to continue to roll over. This occurs when the center of gravity has shifted farther outboard than the center of buoyancy.

Overall Stability – The full range of stability from the initial upright equilibrium stability to the point of vanishing stability.

Positive Stability – The combination of the center of gravity pulling down coupled with the center of buoyancy pushing up creates a righting action that forces the vessel back to its upright position. This occurs when the center of buoyancy has shifted farther outboard than the center of gravity.

Righting Arm – The horizontal distance between the center of buoyancy and the center of gravity.

Righting Arm Curve – The plot of righting arms over a range of heel angles for a given loading.

Righting Moment – The moment or torque created by a positive righting arm multiplied by the vessel's displacement (weight) that is acting to right the vessel.

Ship Stores – All weights such as food or personal items that are consumed during a fishing voyage.

Stability – The ability of a floating object to return to its initial upright position.

Stable Fishing Vessel – A fishing vessel that has sufficient stability to remain upright in current weather and fishing conditions.

Superstructure or Deckhouse – The enclosed portions of the vessel above the highest watertight deck.

Tankage – The consumable fluids, cargo tanks and ballast used during a voyage.

Unstable Fishing Vessel – A fishing vessel that does not have sufficient stability to remain upright in current weather and fishing conditions and will capsize.

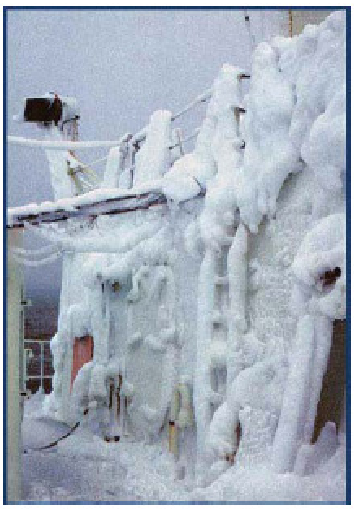
Vessel's Lightship – All of the "fixed" weights on the vessel that do not change during the voyage.

Waterline – The position of the water surface along the hull.

Watertight Envelope – The hull and watertight portions of the superstructure or deckhouses.

Appendix E – Presentation Flyer

Ice Accumulation on Commercial Fishing Industry Vessels



You are invited to attend a presentation on the effects of icing on commercial fishing vessels and the current icing considerations with respect to vessel stability requirements.

The presentation is an overview of an Interactive Qualifying Project completed in conjunction with the US Coast Guard, Office of Vessel Activities (CG-543) by two students from Worcester Polytechnic Institute, Worcester, MA.

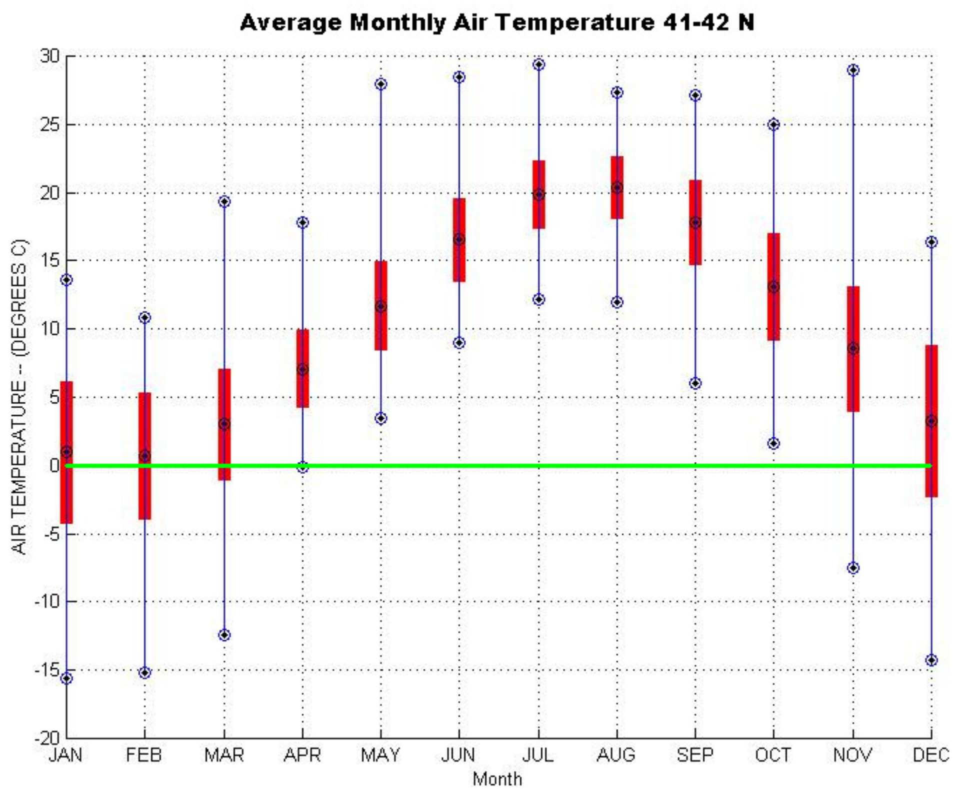
- Marc Chatterton, WPI '10, MGE
- Carson Cook, WPI '10, CE

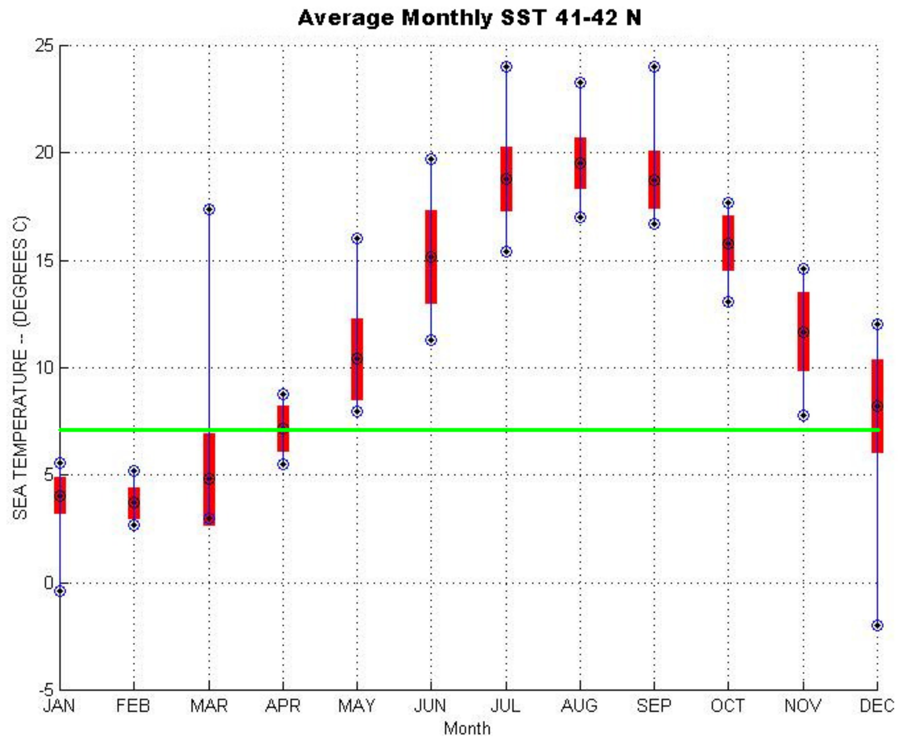
Sponsored by CG-5433, Fishing Vessel Safety Division
Contact: Jack Kemerer, 2-1249

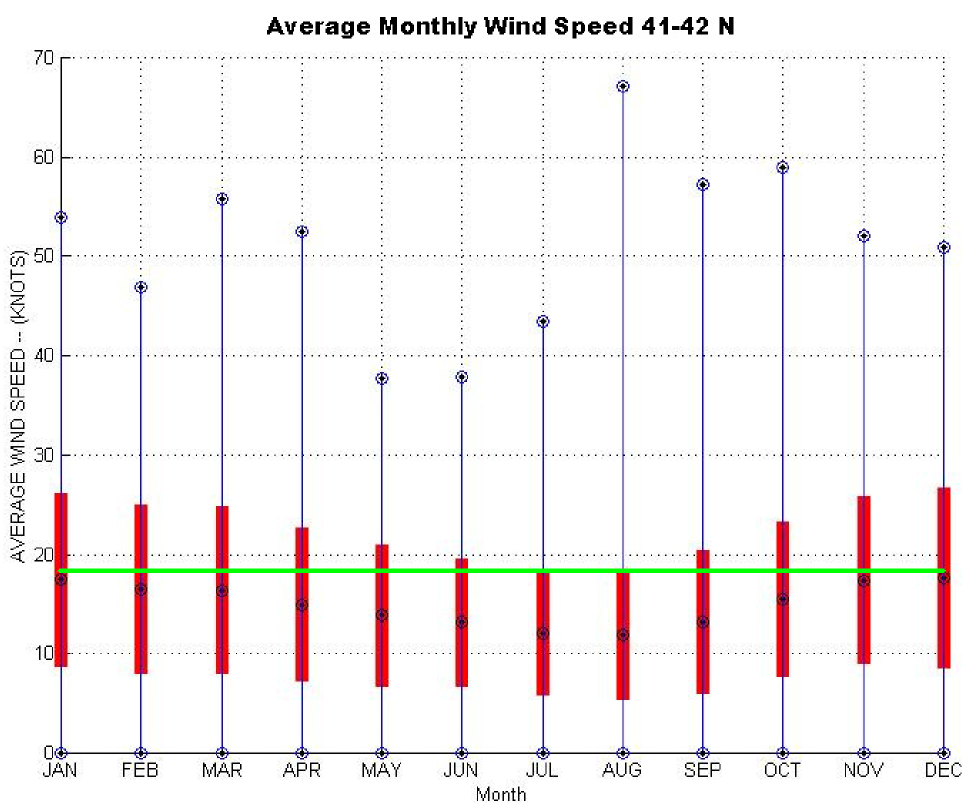
Date: Tuesday, December 16
Time: 9:00 am
Location: Americas Room
4th Floor
#4618

Appendix F –Monthly Icing Averages for the region 41°N-42°N

The following three graphs show the average monthly distribution for air temperature, sea surface temperature (SST), and wind speed. The top and bottom data points represent the maximum and minimum extremes respectively. The red area represents the middle 50% distribution from 25%-75%, and the green line represents the threshold for when icing is more likely to occur. We used these graphs in our preliminary results for finding the proper region to analyze (source: NOAA, 2008).




Average Monthly SST 41-42 N
SEA TEMPERATURE -- (DEGREES C)
25
20
15
10
5
0
-5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month


Average Monthly Wind Speed 41-42 N
AVERAGE WIND SPEED -- (KNOTS)
70
60
50
40
30
20
10
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month

Appendix G – Full Historical Weather Results for the region 41 °N-42 °N

The following table shows the full results for the monthly averages of air temperature, sea surface temperature (SST), and wind speed (WS) for figures 4-4 and 4-5 on pg. 46.

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Max Air	13.6	10.8	19.3	17.8	27.9	28.5	29.4	27.3	27.1	25	29	16.4
Mean Air	1	0.7	3	7.1	11.7	16.5	19.8	20.3	17.8	13.1	8.6	3.3
Min Air	-15.6	-15.2	-12.4	-0.1	3.5	9	12.2	12	6	1.6	-7.5	-14.3
Air Thresh.	0	0	0	0	0	0	0	0	0	0	0	0
Max SST	-2.6	-1.5	-1	0.8	1.2	1.8	1.9	0.6	-0.6	-2.7	-3.2	-3.8
Mean SST	6.1	6.2	9	9.2	7.2	10.8	10.1	5.5	4	5.7	4.5	6.2
Min SST	-8.7	-14.9	-20.6	-4.7	-1.9	-2.6	-3	-4.5	-10.8	-12.4	-14.3	-13
Air Thresh.	7	7	7	7	7	7	7	7	7	7	7	7
Max WS	54	46.9	55.8	52.5	37.7	37.9	43.5	67.1	57.2	58.9	52.1	50.9
Mean WS	17.4	16.5	16.4	15	13.8	13.2	12	11.9	13.1	15.5	17.4	17.7
Min WS	0	0	0	0	0	0	0	0	0	0	0	0
WS Thresh.	18	18	18	18	18	18	18	18	18	18	18	18